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Vlaming Sub-Basin and Mentelle Basin: Environmental Summary

Kriton Glenn, Scott Nichol, Charitha Pattiaratchi, James Daniell, Tara Anderson, Irina Borissova, Andrew Heap, Jonathan Griffin and Melissa Fellows

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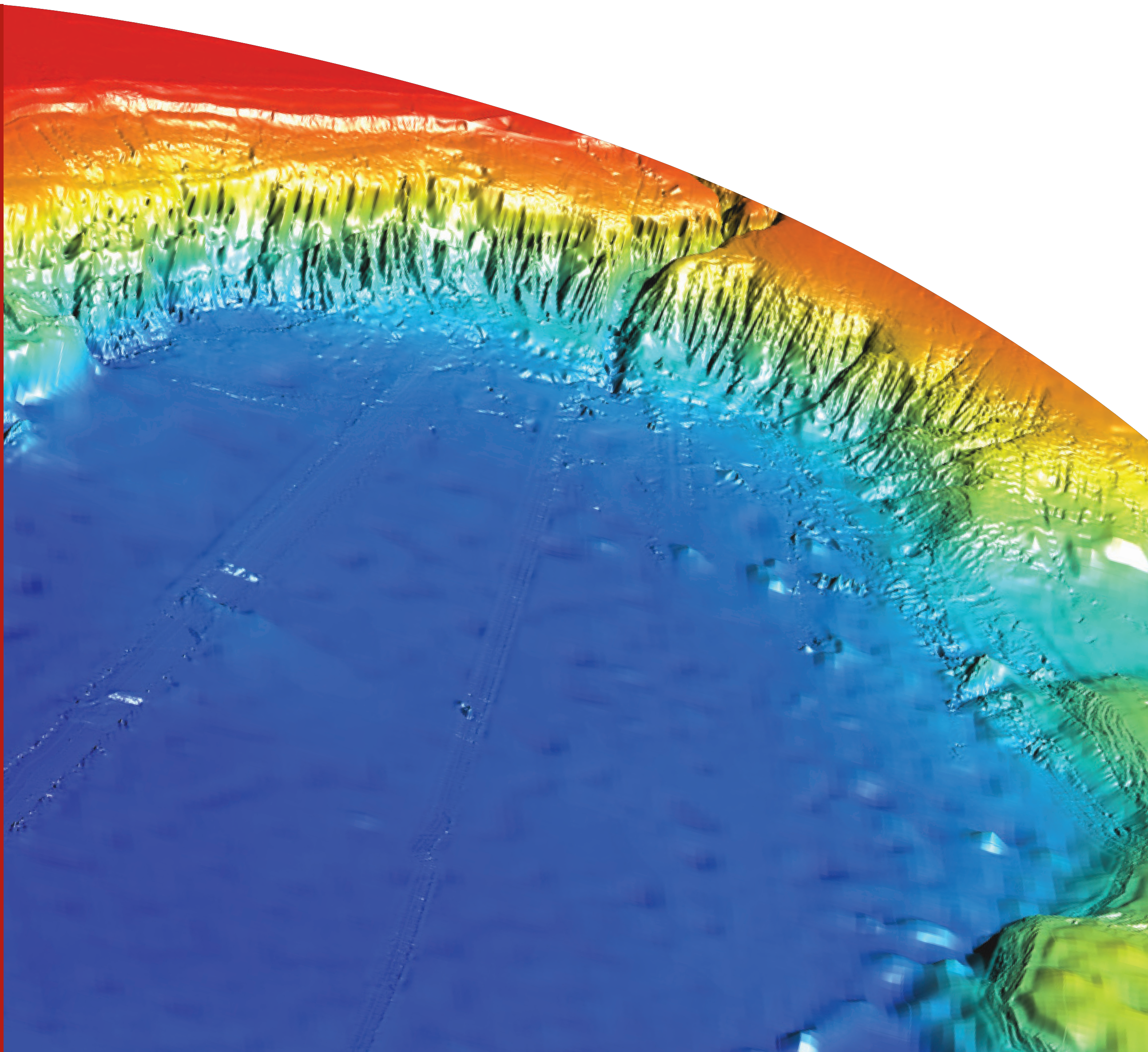

APPLYING GEOSCIENCE TO AUSTRALIA'S MOST IMPORTANT CHALLENGES

Vlaming Sub-Basin and Mentelle Basin: Environmental Summary

GEOSCIENCE AUSTRALIA
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by

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Executive Summary

This report is one of a series of environmental summaries of frontier basins, which are scheduled for petroleum acreage release during the timeframe of the 'Energy Security Initiative' (2007-2011). The aim of these reports is to synthesise the available environmental information to adequately equip the exploration industry to anticipate as many as possible of the environment-related issues that may impact on exploration and potential future production activities.

In particular, this report summarises environmental information relating to the Vlaming Sub-Basin and Mentelle Basin, located on the southwest margin of Australia and bounded by the 112.5°E and 115.7°E meridians, and the 31.3°S and 34.7°S parallels (Figure 1.1). The Vlaming Sub-Basin covers ~16,800 km^2 of seafloor with depths ranging from 0 to 3000 m. The Mentelle Basin is situated in deeper water, ranging from 500 m to 3300 m and includes ~29,400 km^2 of seafloor.

The surface geomorphology of the Vlaming Sub-Basin includes the continental shelf, shelf reefs, the upper continental slope, and the upper half of the Perth Canyon. The Mentelle Basin comprises two structural depocentres that incorporate a marine terrace extending west from the shelf edge, several canyons incised into the lower continental slope, the Naturaliste Trough and part of the Naturaliste Plateau.

The southwest margin is situated in the temperate climatic zone characterised by persistent westerly winds. The Western Australian wild fishery is worth close to $414 million annually and includes twelve major state fisheries managed under the jurisdiction of Western Australia. The region contains both migratory paths and seasonal habitats for 35 species of cetacean. Additionally, the region also supports a high number of invertebrate species, including many that are endemic.

The Vlaming Sub-Basin is a major Jurassic-Early Cretaceous depocentre in the southern part of the Perth Basin lying within the continental shelf and upper slope (0–3000 m water depth). To the west, the sub-basin is bounded by the Vasse Shelf which separates it from the Mentelle Basin. To the east it is bounded by a prominent structural high, the Mandurah Terrace. The Vlaming Sub-Basin contains more than 12 km of basin fill, the bulk of which are syn-rift sediments. Previous studies have shown significant petroleum potential of this basin.

The Mentelle Basin was first mapped as a separate province in 2003 it is a large (36,400 km^2) frontier basin with no previous exploration. It lies in 500 m to 3300 m water depths beneath the outboard part of the Vasse Shelf and the Naturaliste Trough. The basin consists of a shallow-water eastern Mentelle and deep-water western Mentelle depocentres. The shallow-water eastern depocentre of the Mentelle Basin is a large complex half graben with up to 8 km of dominantly syn-rift sediments and a thin post-rift section. The deep-water western depocentre contains at least 7 km of syn-rift and 2.5 km of post-rift section. Interpretation based on limited amount of data available to date indicates that the basin is potentially prospective.

In addition to 4.8 x 10^5 coverage of acoustic reflectivity, core data from 17 wells in the Vlaming Sub-Basin region, Geoscience Australia is also the custodian for multibeam data and presently has 5.8 x 10^5 km^2 of regional sea floor coverage. Metadata for these geophysical data sets and controlled access is available through the Petroleum Information Management System (PIMS) at http://www.ga.gov.au/oracle/npd/.

Geoscience Australia currently holds analytical data for 100 seafloor sediment samples from both basins. This information is discussed in this report and the analytical results from these samples are available through the Marine Sediments Data Base (MARS). This can be accessed at http://www.ga.gov.au/oracle/mars

Given the large water depths over the region, the dominant seabed disturbance mechanism is most likely to be slope failure and related mass-wasting and turbidity currents. Oceanic connectivity within the region is extensive and there is a seasonal link to tropical waters through the Leeuwin Current system and upwelling from the deeper Indian Ocean.

It is difficult to identify biodiversity patterns specific to the Vlaming Sub-Basin and Mentelle Basins, because not enough is known about the species that occur in the region. Based on broad-scale patterns and some detailed knowledge of the geologic and oceanographic characteristics of the area, the following local patterns seem likely.

Given the limited biodiversity information available, the use of seascapes and focal variety analysis offer the opportunity to combine the geological/geophysical, geomorphological, sedimentological and oceanographic information described in this report to highlight regions where the seabed (and by inference biological habitats) are most diverse. This approach has previously been used by the Department of Environment, Water, Heritage and the Arts to guide the design of marine protected areas. In the Vlaming Sub-Basin, Mentelle Basin region, rugose and dissected regions of the mid- to lower-slope show up as regions of greatest seabed habitat heterogeneity. Areas of high seabed habitat heterogeneity have previously been prioritised and targeted as places for the establishment of marine protected areas. Targets for possible marine protected areas also include those that are unique (or relatively uncommon) and/or spatially restricted.

Much of the environmental information described here is also included in a Geographic Information System (GIS) for the Vlaming Sub-Basin and Mentelle Basin, which accompanies this report.

1. Introduction

1.1 AIM AND SCOPE

In August 2006 the Federal Government funded the Energy Security Initiative covering the period 2007-2011. As part of this initiative, Geoscience Australia is compiling environmental summaries of frontier basins scheduled for acreage release in a given financial year. The specific aim of the 'environmental summary for frontier basin' series of reports is to synthesise the available environmental information to adequately equip the exploration industry to anticipate as many as possible of the environment-related issues that may impact on exploration and potential future production activities. The information reported will include locations of gazetted marine parks, fisheries activities, shipping lanes, existing infrastructure, and maritime boundaries where applicable.

Geological and geophysical information relevant to environmental management includes geomorphology, sediments, and oceanography and is being used by the Department of Environment, Water Heritage and the Arts (DEWHA) to design the National Representative System of Marine Protected Areas (NRSMPA). Biological information contained in the reports will include what is known about principal pelagic and benthic species, migratory paths, and any known threatened, endangered or protected species (TEP) under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). It is not the purpose of these environmental summary reports to assess the environmental impact of petroleum exploration and production activities, nor is it to specify the environment-related impediments to the petroleum industry. The purpose is simply to make available to industry a summary of the environmental knowledge pertaining to an area of acreage release so that they are sufficiently informed to make their own assessment.

1.2 REGIONAL OVERVIEW

This report summarises environmental information relating to the Vlaming Sub-Basin and Mentelle Basin, located on the southwest margin of Australia and bounded by the 112.5°E and 115.7°E meridians, and the 31.3°S and 34.7°S parallels (Figure 1.1). The Vlaming Sub-Basin covers ~16,800 km^2 of seafloor with depths ranging from 0 to 3000 m. The Mentelle Basin is situated in deeper water, ranging from 500 m to 3300 m and includes ~29,400 km^2 of seafloor. The surface geomorphology of the Vlaming Sub-Basin includes the continental shelf, shelf reefs, the upper continental slope, and the upper half of the Perth Canyon. The Mentelle Basin comprises two structural depocentres that incorporate a marine terrace extending west from the shelf edge, several canyons incised into the lower continental slope, the Naturaliste Trough and part of the Naturaliste Plateau. The southwest margin is situated in the temperate climatic zone characterised by persistent westerly winds. The Western Australian wild fishery is worth close to $414 million annually and includes twelve major state fisheries managed under the jurisdiction of Western Australia. The region contains both migratory paths and seasonal habitats for 35 species of cetacean. Additionally, the region also supports a high number of invertebrate species, including many that are endemic.

1.3 APPROACH AND CHAPTER OUTLINE

The environmental information for the Vlaming Sub-Basin and Mentelle Basin has been compiled and presented in a manner consistent with the Geographic Information System (GIS) provided with this report. The GIS includes the results of an analysis to obtain representative seascapes. Seascapes are the principal environmental output and in recent years assisted DEWHA with the design and implementation of a National Representative System of Marine Protected Areas for Australia (Chapter 1.1). The following section (Chapter 2) summarises the geological history of the Vlaming Sub-Basin and Mentelle Basin and provides a tectonic and depositional context for the geophysical data and geomorphology of the sub-basin, which are discussed in Chapters 3 and 4, respectively. The surface sediment properties are described in Chapter 5. These sections provide all of the information necessary to characterise benthic habitats. Chapter 6 discusses the oceanographic processes operating in the sub-basin, which influence both the benthic and pelagic ecology described in Chapter 7. Chapter 8 synthesises the information contained in the first seven sections into a seascape map of the Vlaming Sub-Basin and Mentelle Basin.

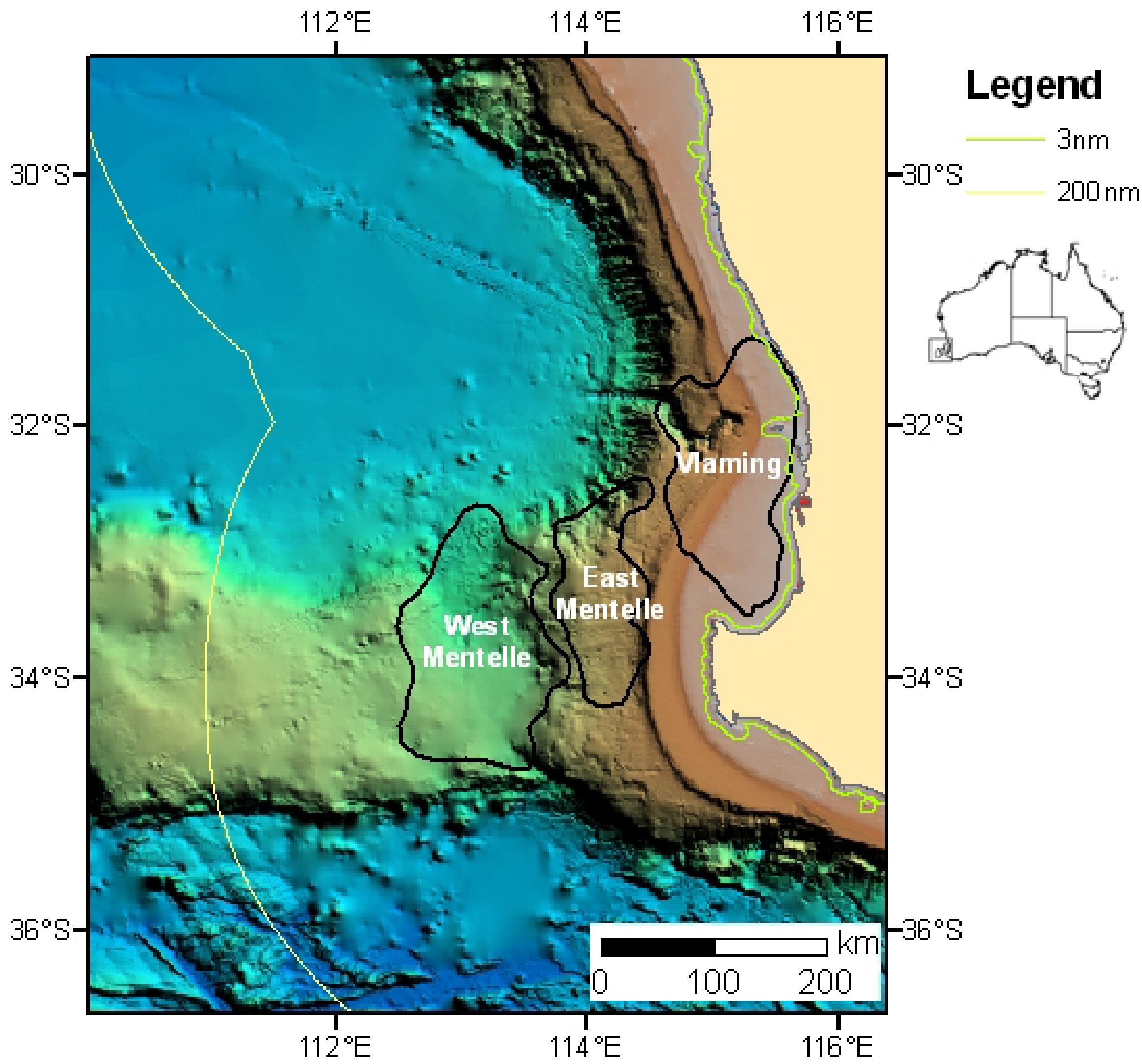


Figure 1.1: *Location and bathymetry of the Vlaming Sub-Basin and Mentelle Basin, southwest margin of Australia. Geographic extents of each basin as follows: Vlaming Sub-Basin – 31.31° to 33.50°S and 114.55° to 115.67°E (area: 16,795 km²); Mentelle Basin– 32.40 ° to 34.73 °S and 112.49° to 114.52°E (area: eastern depocentre 9643 km², western depocentre 19,743 km²).*

2. Geological History

2.1 REGIONAL GEOLOGICAL SETTING

The Perth Basin is an elongate, north to northwest-trending sedimentary basin extending about 1300 km along the southwestern coast of Australia and encompassing both the onshore and offshore (Figure 2.1). It is a structurally complex basin, composed of several sub-basins separated by shallow basement highs (Crostella and Backhouse, 2000, Bradshaw et al., 2003, Norvick, 2003). The Vlaming Sub-Basin is a major Jurassic-Early Cretaceous depocentre in the southern part of the Perth Basin lying within the continental shelf and upper slope (0–3000 m water depth). To the west, the sub-basin is bounded by the Vasse Shelf (Playford et al. 1976) which separates it from the Mentelle Basin. To the east it is bounded by a prominent structural high, the Mandurah Terrace (Iasky and Lockwood, 2004). The Vlaming Sub-Basin contains more than 12 km of basin fill (Crostella and Backhouse, 2000), the bulk of which are syn-rift sediments. Previous studies (Hall 1989, Harris et al. 1994, Miyazaki et al. 1996, Crostella and Backhouse, 2000, Kempton et al, 2002) have shown significant petroleum potential of this basin.

The Mentelle Basin was first mapped as a separate province in 2003 (Bradshaw et al., 2003, Borissova, 2002). Prior to that, the area was regarded to be part of the Naturaliste Plateau volcanic province (Coleman et al, 1982, Storey et al, 1992). The Mentelle Basin is a large (36,400 km^2) frontier basin with no previous exploration. It lies in 500 m to 3300 m water depths beneath the outboard part of the Vasse Shelf and the Naturaliste Trough (Figure 2.1). The basin consists of a shallow-water eastern Mentelle and deep-water western Mentelle depocentres. The shallow-water eastern depocentre of the Mentelle Basin is a large complex half graben with up to 8 km of dominantly syn-rift sediments and a thin post-rift section. The deep-water western depocentre contains at least 7 km of syn-rift and 2.5 km of post-rift section. Interpretation based on limited amount of data available to date indicates that the basin is potentially prospective.

2.2 STRUCTURAL ELEMENTS

The Vlaming Sub-Basin and Mentelle Basin structurally belong to the extensional system on Australia's south-western margin formed during the Palaeozoic to Mesozoic rifting of eastern Gondwana. The complex architecture of the Vlaming Sub-Basin is a result of northeast-southwest extension in the Permian followed by predominantly east-west extension in the Middle Jurassic–Early Cretaceous (Harris, 1994). It is underlain by Proterozoic igneous and metamorphic rocks of the Pinjarra Orogen that formed as an intercontinental mobile belt between Australian and Indian parts of eastern Gondwana (Collins, 2003). Major north-south and northwest-southeast oriented faults and shear zones in the basement seem to control orientation of the major Jurassic–Cretaceous structures within the Vlaming Sub-Basin. The northwest-southeast trending Turtle Dove Transfer and Harvey Transfer define first order segmentation of the margin (Figure 2.1). They share the same orientation as Proterozoic shear zones in the Yilgarn Craton which are long-lived crustal structures that underwent Archean, Mesoproterozoic and Phanerozoic reactivation (Dentith et al, 1994). It is likely that these basement structures controlled the segmentation of the Vlaming Sub-Basin and possibly of the Mentelle Basin. Leeuwin and Naturaliste Fracture Zones bounding the Naturaliste Plateau share the same orientation as Transfer Zones in the Vlaming Sub-Basin.

In the Vlaming Sub-Basin the syn-rift faulting produced a series of half-grabens and associated anticlinal rollovers with collapse systems on the updip flanks (Spring and Newell, 1993). Anticlinal systems (arches) are mostly located along the eastern part of the sub-basin and are 20-25 km wide (Figure 2.2). These arches have been partly reactivated prior to the breakup, which resulted in increased fault density within these structures.

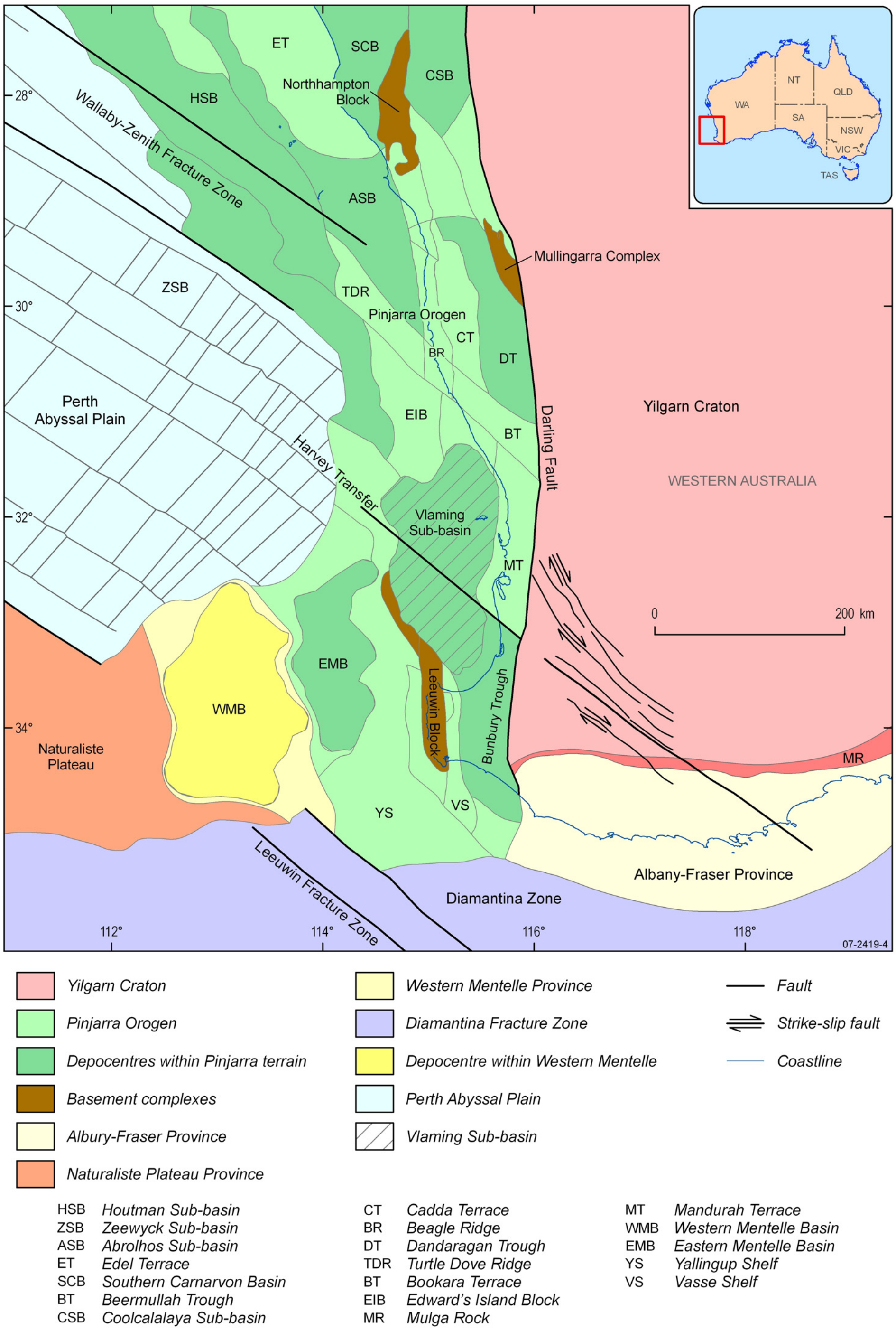


Figure 2.1: *Geological setting of the Vlaming Sub-Basin and Mentelle Basin.*

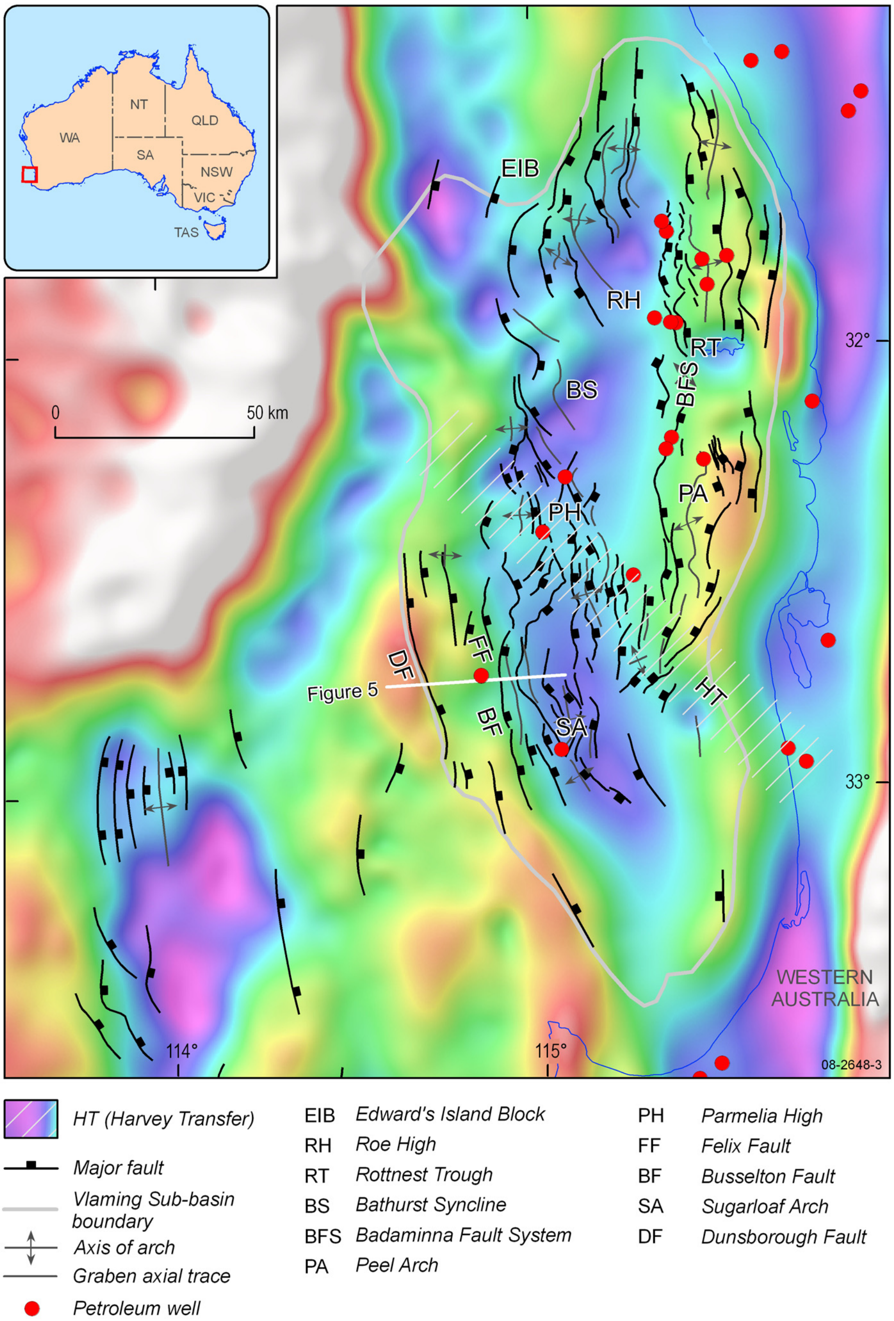


Figure 2.2: *Structural elements of the Vlaming Sub-Basin and eastern Mentelle Basin underlain by Bouguer gravity image.*

Recent fault mapping in the Mentelle Basin has shown that its architecture is consistent overall with prevalent fault orientations in the Vlaming Sub-Basin. The eastern Mentelle depocentre is characterised by steep, westerly dipping synrift sequences with most faults dipping to the east. None of the faults appear to have been reactivated after the breakup. Maximum sediment thickness in this depocentre (8 km) corresponds to water depths of about 1300m in the middle part of the continental slope.

The deepwater depocentre of the western Mentelle Basin is significantly less faulted than the Vlaming Sub-Basin and the eastern Mentelle. Seismic interpretation suggests that the main half-graben underpinning the western Mentelle depocentre dips both to the west and the south, similar to some depocentres within the Vlaming Sub-Basin but on a larger scale. The post-rift section in the western Mentelle depocentre is much thicker (up to 2.5 km) than in the eastern Mentelle and is largely undeformed.

2.3 TECTONIC EVOLUTION

Rifting and basin development on the southwestern margin commenced in the Permian and was characterised by several phases of extension and thermal subsidence. The Darling Fault forms the eastern bounding fault system of the Perth Basin, controlling its overall north-south orientation. It originated as a shear zone during the Archaean (Blight et al, 1981) and was reactivated to form a major rift-border fault to the incipient Perth Basin during the Early Permian (Crostella and Backhouse, 2000).

Northeast-southwest oriented Permian extension was followed by a long period of subsidence in the Permo-Triassic (Harris et al., 1994). In the South Perth Basin, a major Permian depocentre is located onshore between the Darling and Busselton faults beneath the Bunbury Trough and contains up to 4 km of Permian strata overlain by about 2.5 km of Triassic sediments (Iasky and Lockwood, 2004). It is not known whether any Permian or Triassic strata are present in the Mentelle basin.

The main Jurassic depocentre in the Perth Basin, the Vlaming Sub-Basin, formed during east-west extension in the Early Jurassic followed by northwest-southeast extension in the Late Jurassic (Harris et al., 1994). During these extensional episodes thick fluvial successions interbedded with coal beds have been deposited across the basin. Periods of thermal subsidence are characterised by the increased presence of lacustrine and deltaic sediments. Comparison of the major sequences in the Vlaming Sub-Basin and the Mentelle Basin suggests that their basin phases are very similar. In the absence of well data in the Mentelle Basin its basin history and stratigraphy have been interpreted using the Vlaming Sub-Basin as an analogue.

In the Late Jurassic–Early Cretaceous the Mentelle Basin and southern Perth basin were part of the complex continental rift system within Eastern Gondwana. Rifts along the Perth Basin margin formed along the future breakup boundary between Australia and Greater India, whereas the Mentelle Basin was close to the triple junction with Antarctica (Figure 2.3), where the breakup was hindered by the Naturaliste Plateau – a large continental fragment extending to the west of the Mentelle Basin Rift. The Naturaliste Plateau appears to be conjugate to the Bruce Rise on the Antarctic margin. Seismic and magnetic data from the Antarctic margin indicate that the breakup between these two features occurred in the Early Cretaceous (Gaina et al., 2007) close to the time of the main breakup on the southwestern margin. However, this rifling between Australia and Antarctica failed and resumed only in the Santonian (Sayers et al. 2001), when the breakup took place along the whole southern margin.

On the western margin Jurassic–Early Cretaceous extension culminated in the breakup between Australia and India during the Valanginian (Harris, 1994; Mory and Iasky, 1996; Quaife et al, 1994; Song and Cawood, 2000; Norvick, 2003). Uplift prior to breakup led to wide-spread erosion creating a prominent, often angular, unconformity showing up to 1200 m relief. The Valanginian breakup was associated with volcanism that produced basalt flows such as the Bunbury Basalt (Crostella and Backhouse, 2000). Analysis of regional seismic data shows that lava flows frequently occur in palaeo-topographical lows of the Valanginian unconformity in the southern part of the Vlaming Sub-Basin and throughout the Mentelle Basin. It appears that this volcanism was not as voluminous as that further north on the Exmouth-Wallaby volcanic margin (Symonds et al, 1998), where basaltic flows reach several hundred metres in thickness and completely overprint pre-existing relief and sedimentary structures. Lava flows in the Vlaming Sub-Basin /Mentelle region are more likely to be relatively thin, no more than 100 m thick.

After the breakup as a result of regional thermal subsidence sedimentation in the Vlaming Sub-Basin /Mentelle area took place in gradually deepening basins. The depositional environment changed from deltaic to shallow marine in the Hauterivian to Campanian and to open marine in the Campanian to Tertiary. When open marine conditions were established across the whole southwest margin, depositional rates decreased and a number of canyons and channels developed on the continental slope. Major canyon incision events in the Paleocene, Eocene and Oligo-Miocene are evident on seismic images.

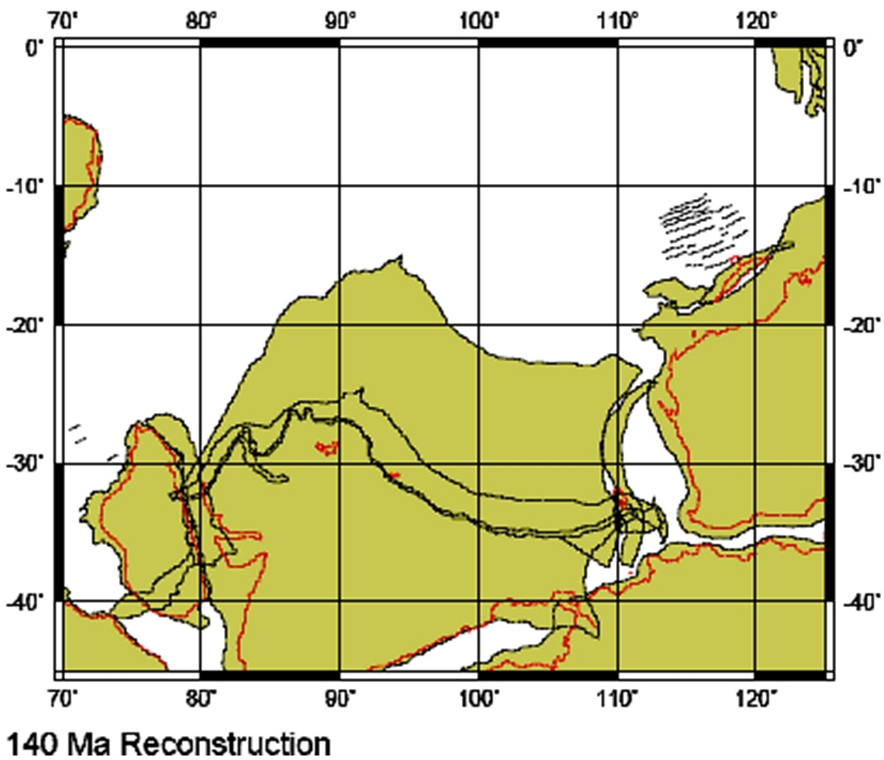


Figure 2.3: *Plate tectonic reconstruction at the time of the breakup on the southwestern margin between Australia and Greater India.*

2.4 TECTONOSTRATIGRAPHY

Stratigraphy of the Vlaming Sub-Basin has been discussed by Crostella and Backhouse, 2000, Le Blanc Smith and Kristensen, 1998, Marshall et al., 1993, Miyazaki et al, 1996, Mory and Iasky, 1996, Seggie, 1990 and Spring and Newell, 1993. Recent Geoscience Australia studies resulted in a significant revision of the tectonostratigraphic framework for this basin (Figures. 2.4, 2.5; unpublished results). The following seven megasequences corresponding to major basin phases have been identified in the Vlaming Sub-Basin and the adjacent onshore south Perth Basin:

- Permian (equivalent to Sue group onshore): initial extension, non-marine, coaly rift basin-fill
- Permo–Triassic (equivalent to Sabina Sandstone and Lesueur Sandstone): occurs at depth in the southern Vlaming Sub-Basin , but not well imaged on the seismic data due to a combination of the depth of burial and lack of lithological contrast with the overlying thick Jurassic continental succession. Sandstone-dominated thermal subsidence basin-fill.
- Early to Mid-Jurassic (Cattamarra Coal Measures, Eneabba and Cadda Formations): major extensional basin phase followed by thermal subsidence. Deposition of fluviatile sandstones interbedded with dark coloured, carbonaceous mudstones and thick coal seams
- Late Jurassic – Early Cretaceous (Yarragadee Formation, Parmelia Group): two separate extensional pulses. Deposition of fluvial sandstones, lacustrine mudstones and deltaic sediments. Deltaic progradation in the northern part of the Vlaming Sub-Basin.
- Early Cretaceous (Warnbro Group): thermal subsidence. Establishment of shallow marine and deltaic depositional environments over much of the region. Major deltaic progradation occurred in the northern and southern Vlaming Sub-Basin. Deposition of sandstones and marine shales.

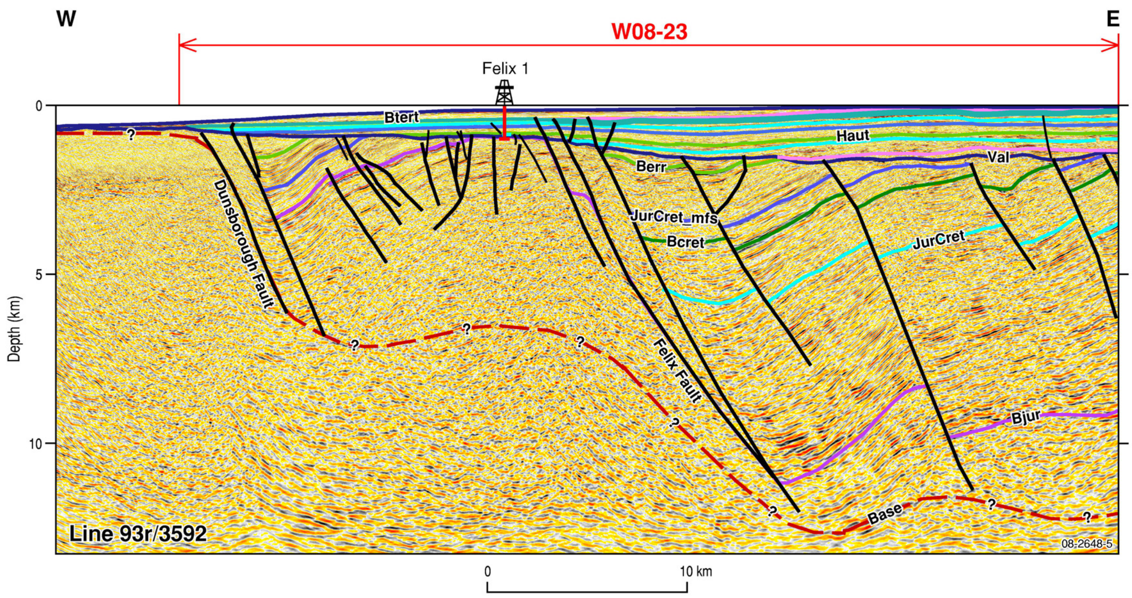


Figure 2.4: *Interpreted seismic section across the southern part of the Vlaming Sub-Basin basin. For location see Figure 2.2. For ages and definitions of the mapped sequences see Figure 2.5.*

- Mid to Late Cretaceous (Coolyena Group): Establishment of a shallow marine shelfal environment across the basin. Deposition of pelagic siliciclastics.
- Cainozoic: Gradual change from shallow marine to open marine environments with mixed siliciclastics and carbonate shelfal facies.

As the Mentelle basin has never been drilled, seismo-stratigraphic correlations are made to the DSDP well 258 on the Naturaliste Plateau and to the exploration wells in the southern Vlaming Sub-Basin. However, direct correlations are possible only for the Late Cretaceous to Recent section based on DSDP drilling results. The Mentelle Basin is separated from the Vlaming Sub-Basin by a prominent basement high (Vasse Shelf) and therefore the age of the older section has been deduced from correlation of basin phases and analysis of seismic facies.

Valanginian breakup unconformity is a reliable marker throughout the study area. This boundary is expressed as a prominent angular unconformity in the eastern Mentelle and as a major onlap surface with wide-spread volcanics in the western Mentelle. The synrift section both in the eastern and the western Mentelle Basin consists of two growth packages corresponding to two extensional phases. The basal synrift sequence (synrift 1) has been correlated to the Yarragadee–Base Parmelia Group (Late Jurassic–Early Cretaceous) and the second synrift sequence (synrift 2) to the Parmelia Group–Warnbro Group (Berriassian) in the Vlaming Sub-Basin (Nicholson et al., 2008, Figure 2.5). Both extensional phases fall within the Late Jurassic–Early Cretaceous supersequence. The sequence beneath synrift 1 directly overlying the basement does not display obvious growth characteristics and could represent pre-rift sediments. This sequence cannot be reliably correlated to any of the Vlaming Sub-Basin sequences and potentially could be Permian, Triassic or Early Jurassic in age.

The age of the post-rift section has been interpreted here from DSDP site 258 located on the eastern part of the Naturaliste Plateau. Site 258 recovered 411 m of Cretaceous sediments overlain by 114 m of Miocene to Recent nannofossil ooze. The lowest part of the Cretaceous consists of 11 m of glauconitic detrital sandstone and silty clay followed by 251 m of mid-Albian to Cenomanian ferruginous detrital clays. The Albian section mapped in the western Mentelle Basin thickens toward its central part where it reaches about 1100 m and thins out to about 200 m on the flanks. Albian sediments are very thin or absent in the Vlaming Sub-Basin, which suggests that in the period between the breakup in the Valanginian and the mid-Albian depositional environment in the two basins became quite different. While the Vlaming Sub-Basin remained relatively shallow until Late Cretaceous, a deep-water environment became established in the Mentelle Basin by the Cenomanian.

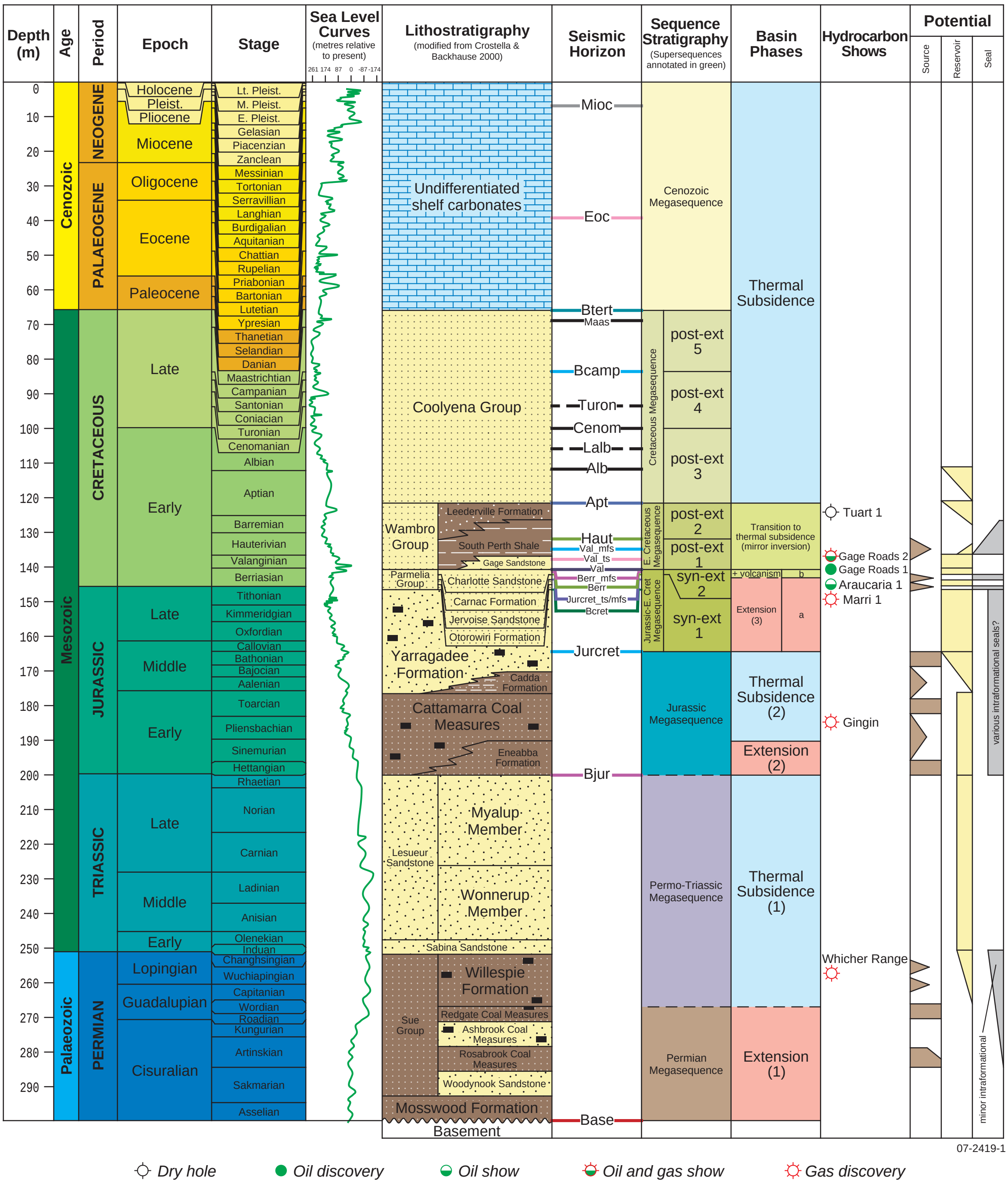


Figure 2.5: *Stratigraphic chart for the Vlaming Sub-Basin, showing major seismic sequences, tectonic history and petroleum systems elements (compiled by Geoscience Australia, 2008).*

3. Geophysics

3.1 INTRODUCTION AND DATA SOURCES

This section summarises the availability and coverage of geophysical datasets to assist with environmental and geological assessment. The key data types described are bathymetry, acoustic reflectivity, and sub-bottom profiles. The aim is to make industry aware of the environmental data available within the Mentelle

Basin and Vlaming Sub-Basin. A description of the stratigraphy and geomorphology interpreted from these data sets is contained within Sections 2 and 4, respectively.

3.2 BATHYMETRY

Bathymetric information is collected using several techniques (Table 3.1). Geoscience Australia's (GA) bathymetric data holdings consist of ship-track (single-beam) bathymetry, multibeam sonar bathymetry, digitised soundings from hydrographic charts, laser airborne depth sounder (LADS) data, predicted bathymetry from satellite altimetry, and other geophysical measurements. Geoscience Australia combines and interpolates these datasets to provide bathymetric grids for marine zone management, research and acreage release areas at a nominal resolution of 0.0025 degrees (~250m) (Figure 3.1).

Table 3.1: Methods of bathymetric data acquisition.

Technique	Examples	Depth Range	Advantages	Limitations
Leadline	Leadline	0-50 m	Very inexpensive; can be used to collect small seabed samples	Inaccurate due to wind and currents. Pre echo-sounder technology
Airborne/ Satellite Remote Sensing	Landsat TM, IKONOS	0-25 m, clear water only (50 m max.)	Very large areas can be assessed	Limited optical penetration; many features cannot be optically distinguished
Airborne bathymetry	LIDAR – LADS, SHOALS;	0-50 m, clear water only	Very rapid, high accuracy coverage	Expense of aircraft operation, turbid waters, bad weather, ~30m depth limit
Single-beam acoustics	High to low frequency echo-sounders (~200-3.5 kHz)	Up to full ocean depth	Depth range, can provide subsurface information;	Requiring multiple, closely spaced lines
Multibeam sonar	Simrad EM300 RV Southern Surveyor	1-1000's m	Large swath coverage, bathymetry and backscatter	Large expense and data volumes,
Satellite altimetry	ETOPO2	Up to full ocean depth	Global	Low spatial resolution and inaccurate in places

Much of the historical bathymetric data comprises single-beam or ship track bathymetry. In these systems, a transducer produces an acoustic signal (typically 3.5 kHz – 200 kHz) that propagates through the water column directly below the ship. The two-way travel time can be converted to depth if the velocity of sound in water is accurately known. Many of the bathymetric soundings held by GA were acquired using single beam technology and recorded on Australian Hydrographic Survey (AHS) fairsheets, and Admiralty Charts (metadata for AHS fairsheets and charts may be found at http://www.hydro.gov.au/asdd/source/).

The density of ship-track survey lines is highly variable, and in some areas data points can be tens of kilometres apart. By contrast, areas of LADS and swath bathymetry coverage have a high density of soundings (with LADS data restricted to depths <50 m). Fairsheet (mainly single-beam data) is available for most areas of the continental shelf at relatively low data density.

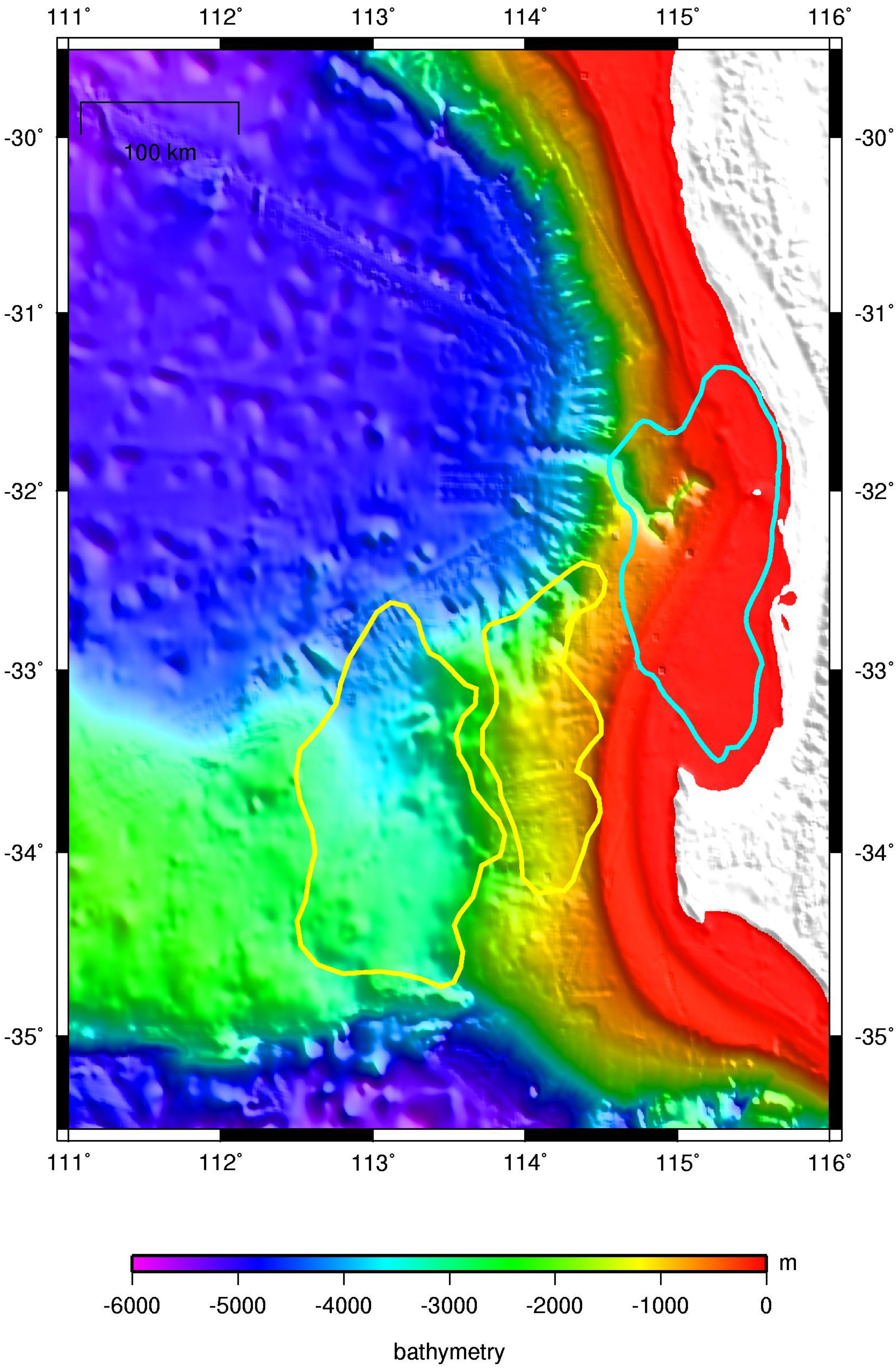


Figure 3.1: *Bathymetry compilation for the Mentelle (yellow) Basin and Vlaming (light blue) Sub- Basins.*

Multibeam sonar mapping systems record a swath comprising up to 200 beams that allow large areas of the seabed to be mapped with high accuracy (Hughes Clarke et al., 1996). The acoustic beams form a swath that fans out up to several times the water depth. Corrections and post-processing are made for sound velocity, ship motion (heave, roll, and pitch), and tidal variation to produce a highly accurate bathymetric model of the seabed. Various multibeam sonar systems exist and can be used in as little as a few metres water depth, to full ocean depth with corresponding differences in horizontal and vertical resolution.

Multibeam sonar systems provide the highest resolution bathymetry information within the Vlaming Sub-Basin / Mentelle Basin, are a key tool for understanding the morphology and habitats of the seabed in those regions (see section 4). The Vlaming Sub-Basin / Mentelle Basin have an extensive coverage of deep water multibeam bathymetry (Figures 3.2 – 3.4.). Twenty Seven surveys in total pass through the region (Table 3.2) with one survey specifically targeting the geomorphology, surficial geology, and shallow stratigraphy of the region (Heap et al. 2006). Eleven surveys are transit data sets acquired opportunistically as research vessels pass through Australian waters though a number of other surveys are transits to and from research areas outside the Mentelle/Vlaming region (such as surveys 0236, 0245, and 0265).

The un-interpolated bathymetry grid presented in Figure 3.3 is provided at a resolution of ~250 m and shows the actual coverage of multibeam bathymetry in the Vlaming Sub-Basin / Mentelle Basin. The data densities shown in Figure 3.4 show the highest data densities occurring in shallow water and where survey lines overlap. The 0293_Mentelle survey targeted numerous areas in water depths of less than 1000 m. Datasets from this survey typically have a resolution better than 50 m. Other surveys that have targeted benthic habitats on the continental slope in the region (surveys 0296 and 2390) also provide relatively high resolution datasets. Multibeam sonar systems provide highest resolution bathymetry information within the Vlaming Sub-Basin / Mentelle Basin and as such are a key tool for understanding the morphology and habitats of the seabed in those regions. Surveys that have used multibeam sonar surveys are detailed in Table 3.2. A description of the morphology of the Mentelle Basin region, based largely on multibeam bathymetry, is contained in chapter 4 of this report.

Table 3.2: Marine surveys within the Vlaming Sub-Basin / Mentelle Basins. MB - multibeam bathymetry, BS - acoustic backscatter, SS - sidescan and SBP - sub bottom profiler. Most Geoscience Australia surveys have post cruise reports associated that document data acquisition and preliminary data interpretation. Most Geoscience Australia surveys have post cruise reports that document data acquisition and preliminary data interpretation. Surveys without reports were run by organisations other than Geoscience Australia.

Survey	Ship	Transit	MB	BS	SS	SBP	Report
2352_rottnest	RV Cook	N	Y	N	N	N	Hughes Clarke et al. 1990
0157_adedav	Latalante	Y	Y	N	N	N	No
1153_west08mv	RV Melville	Y	Y	N	N	N	No
1179_perth_canyon	Knorr	N	Y	Y	Y	N	No
1166_west09mv	RV Melville	N	Y	N	N	N	Cochran and Sempere 1995
1274_west10mv	RV Melville	Y	Y	N	N	N	No
1173_bmrg05mv	RV Melville	Y	Y	N	N	N	No
1154_bmrg06mv	RV Melville	Y	Y	N	N	N	No
1431_sojn04mv	RV Melville	Y	Y	N	N	N	No
1175_sojn05mv	RV Melville	Y	Y	N	N	N	No
0208_margau	MarionDufresne	N	Y	N	N	N	Royer and Beslier, 1998
2367_ew0112	RV Ewing	Y	Y	Y	N	N	No
0235_ew0113	RV Ewing	Y	Y	Y	N	N	No
2305_ew1114	EV Ewing	Y	Y	Y	N	N	No
0236_auscan1	MarionDufresne	N	Y	N	N	N	Hill and De Deckker 2004
0245_auscan2	MarionDufresne	N	Y	N	N	N	Hill and De Deckker 2004
2354_EM300trials	RV Southern Surveyor	N	Y	Y	Y	N	No
2309_mr03k4_16	RV Mirai	Y	Y	Y	Y	N	No
0265_bremer	RV Southern Surveyor	N	Y	Y	Y	N	Exon et al. 2004
0296_wabio	RV Southern Surveyor	N	Y	Y	Y	Y	No
0293_mentelle	RV Southern Surveyor	N	Y	Y	Y	Y	Heap et al. 2006
2383_natrocks	RV Southern Surveyor	N	Y	Y	Y	Y	No
2390_wabio2	RV Southern Surveyor	N	Y	Y	Y	Y	No
2400_leeuwin_current	RV Southern Surveyor	N	Y	Y	Y	N	No
2406_mesoeddies	RV Southern Surveyor	N	Y	Y	Y	N	No
2433_sst03_2007	RV Southern Surveyor	N	Y	Y	Y	Y	No
2434_wa_pelagic	RV Southern Surveyor	N	Y	Y	Y	N	No

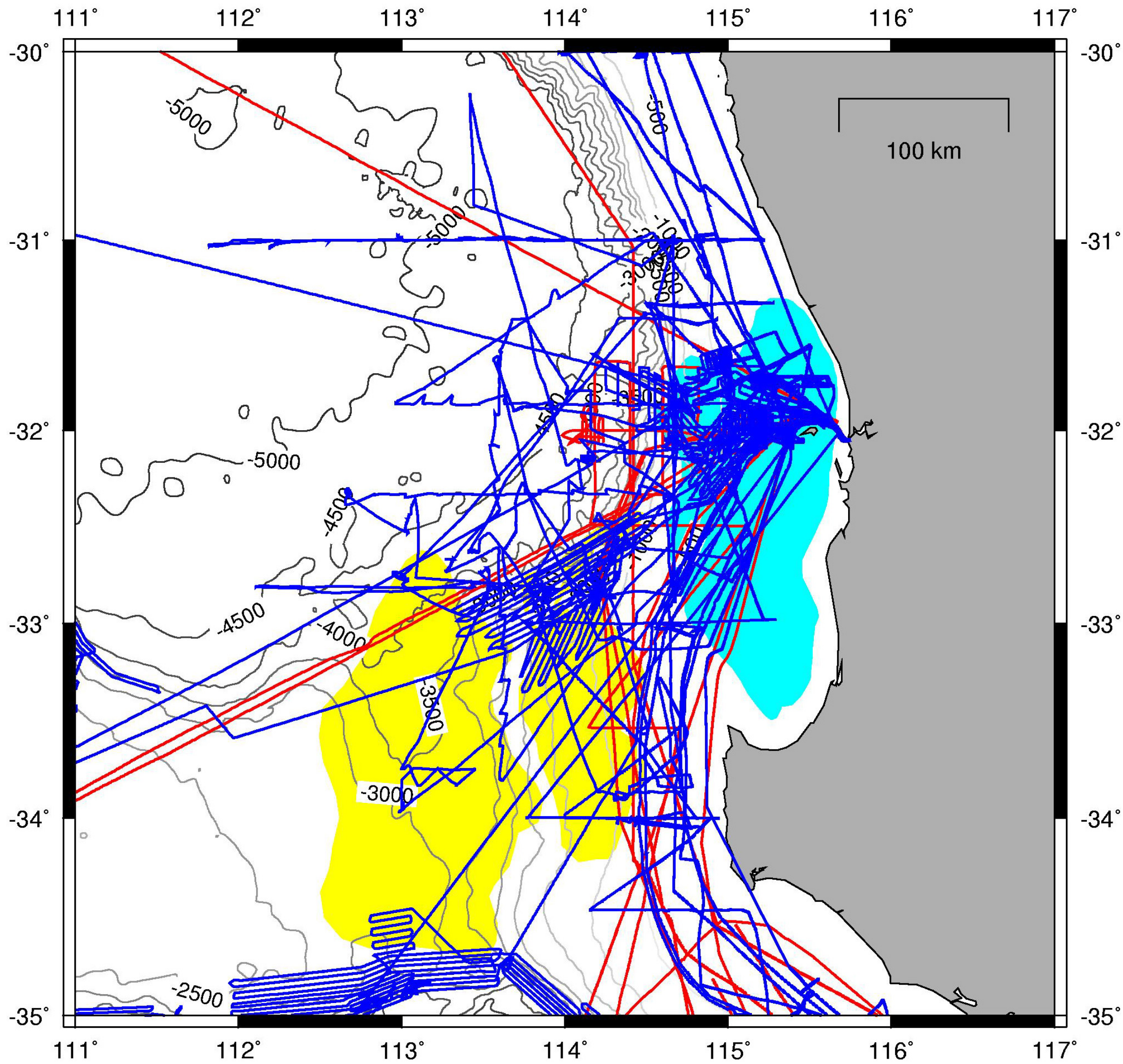


Figure 3.2: *Coverage of multibeam sonar surveys (all tracks), red tracks are surveys that do not have backscatter or sidescan datasets associated with them. The extent of the Mentelle Basin is indicated by the yellow polygon, and the Vlaming Sub-Basin by the light blue polygon.*

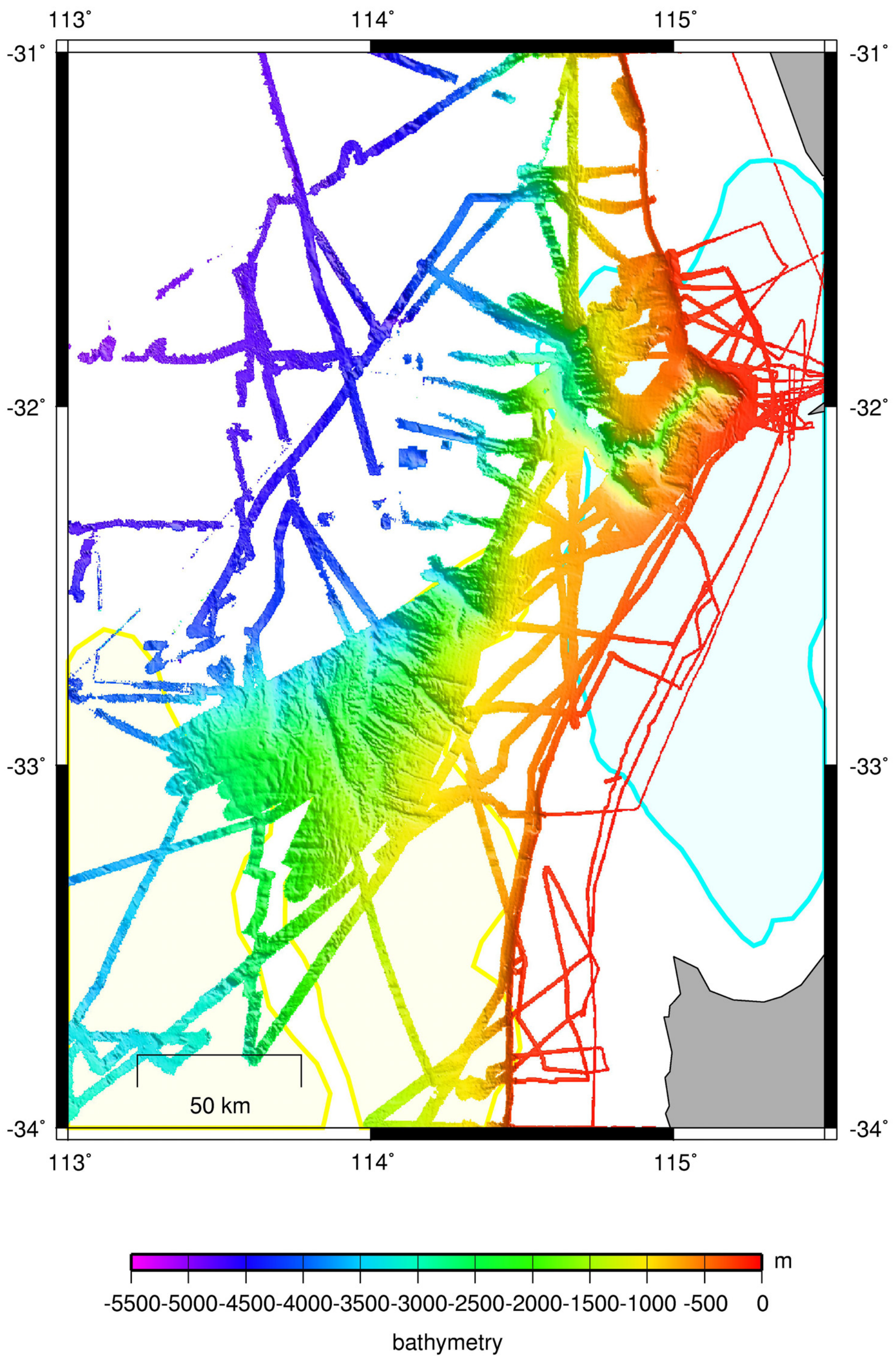


Figure 3.3: *Multibeam bathymetry compilation for the Vlaming Sub-Basin and Mentelle basins (blue and yellow respectively) and adjacent regions.*

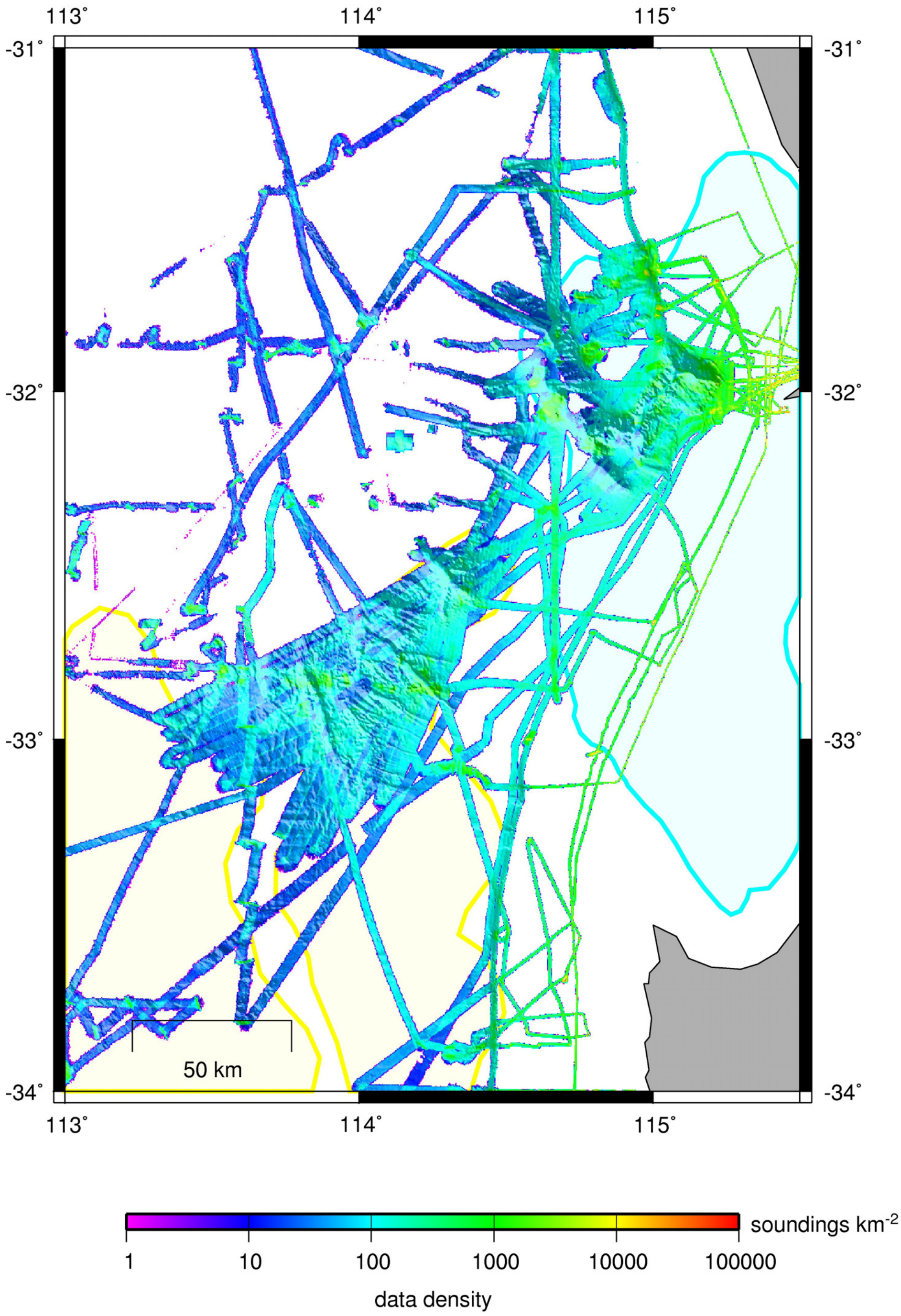


Figure 3.4: *Multibeam bathymetry data density for the Vlaming Sub-Basin and Mentelle Basin (blue and yellow respectively) and adjacent regions.*

3.3 ACOUSTIC REFLECTIVITY (SIDESCAN AND BACKSCATTER)

Multibeam sonar systems acquire both bathymetry and acoustic reflectivity. Acoustic reflectivity carries important information about the physical properties of the seabed such as roughness, hardness and homogeneity (Beaudoin et al., 2002). Reflectivity datasets can assist in seafloor characterisation (habitats/substrate types) and hence are an important and complimentary dataset to bathymetry.

The acoustic backscatter registered by sidescan sonars is normally logged as two time series of intensity values, one for the port side the other for the starboard side, recorded at the reception transducer (Tyce, 1986). In contrast, multibeam sonars register the acoustic backscatter in three different forms:

1. average backscatter strength for each beam;
2. a time series of backscatter strength around the detection point of each received beam;
3. two time series of backscatter strength (port and starboard) for each received ping, which will generate data very similar to a sidescan (Beaudoin, 2002).

Multibean sonars, like the Simrad EM300 on the RV Southern Surveyor, acquire both the average beam strengths (i.e. type 1), and ‘pseudo-sidescan’ (i.e. type 3). As the resolution achieved by the multibeam sonar sidescan is of a comparable resolution to stand alone sidescan systems they are considered synonymous for this review.

Sound attenuates (decays) through the water column and through interactions with the seabed. As a result, a number of biases are introduced into backscatter and sidescan datasets during acquisition. These biases need to be corrected before these data can be used for seabed characterisation and habitat analysis (Fonseca & Calder, 2005; Fonseca & Mayer, in prep). The distortions are generated by:

- Variable Transmit power
- Variable Receiver gains
- Variable Pulse widths
- Changing areas of seabed insonification
- Attenuation in the water column
- Seafloor slope
- Sediment angular response
- Spherical spreading
- Beam patterns
- Speckle noise
- Applied time varying gain (or TVG) or Lambertian corrections
- Slant range
- Positioning

Within the Vlaming Sub-Basin / Mentelle Basin, most surveys have both sidescan and backscatter data recorded with multibeam sonar bathymetry (Figure 3.1). At present this data is not combined into interpolated grids due to the associated distortions in the data and lower coverage of data compared to bathymetry (when data types other than multibeam are taken into consideration).

Rudimentary processing of some data from the Mentelle basin indicated that this is a potentially valuable dataset for seabed characterisation (Figure 3.5). Within the Mentelle Basin, areas of high backscatter (yellow and orange) are restricted to the inner shelf and canyons and are possibly related to coarse sediment or bedrock outcrops. Regions of moderate to low backscatter (green and blue) are typically restricted to the outer shelf and slope and are possible a result of pelagic sediment drapes and fine sediment associated with low energy environments in the Vlaming Sub-Basin / Mentelle regions.

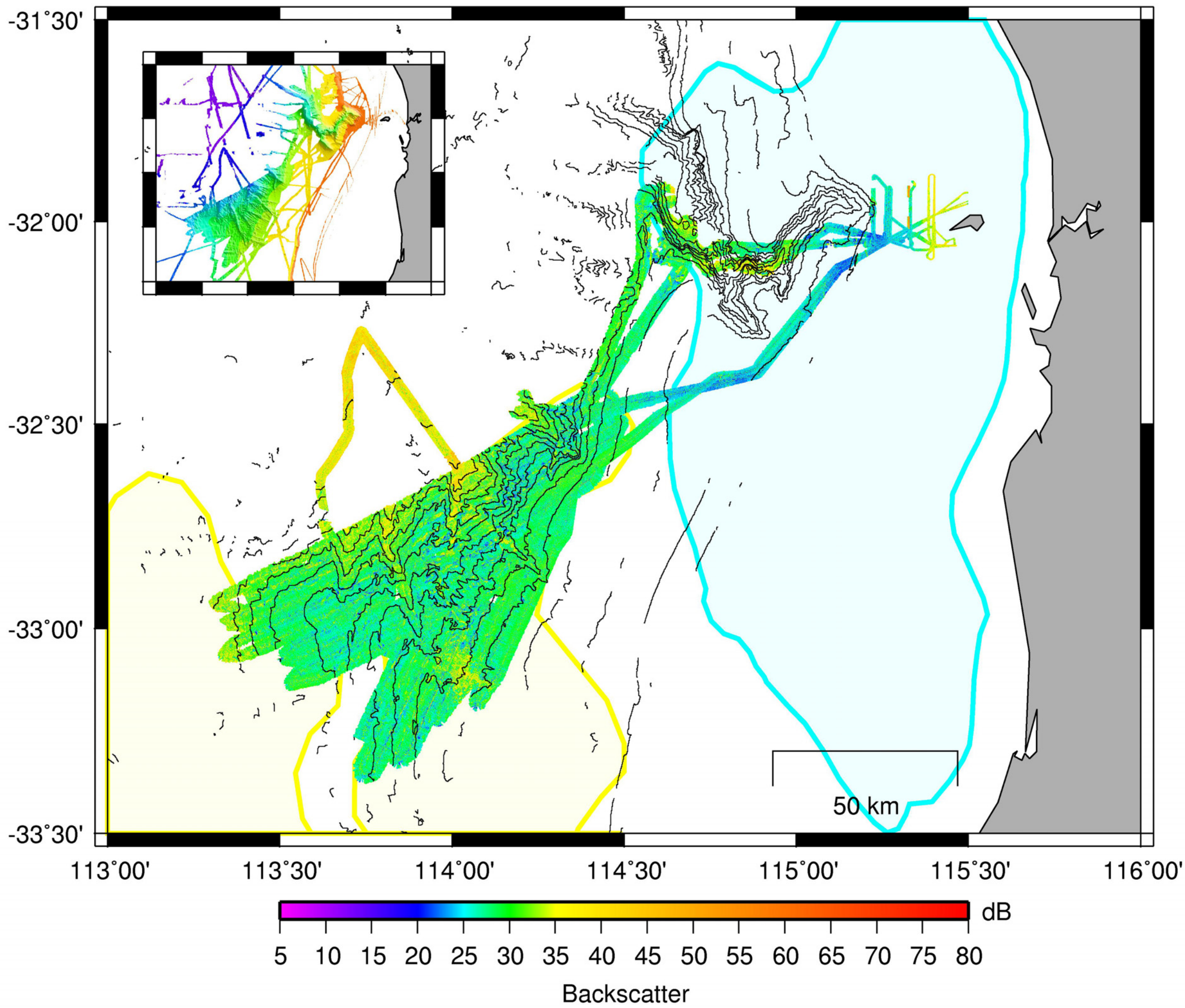


Figure 3.5: *Backscatter map of the Vlaming Sub-Basin (blue) and Mentelle (yellow) Basin. Contours are used to highlight the presence of canyons in the region. A bathymetry map for the same region is used to illustrate the canyon morphology in the region (inset).*

3.4 SUBBOTTOM PROFILER

Subbottom profiling (SBP) systems are used to identify and characterize layers of sediment or rock under the seafloor. The technique used is similar to a simple echosounder. A transducer emits a sound pulse vertically downwards towards the seafloor, and a receiver records the return of the pulse once it has been reflected off the seafloor. Parts of the sound pulse will penetrate the seafloor and be reflected off of the different bottom layers. The data that is obtained using this system provides information on these floor sediment layers.

Sub bottom profile data are generally delivered in the SEGY binary format (.sgy) with one file per seismic line. Parums (2007) provides a summary of the SBP data holdings at GA, including general information about the surveys, maps showing the SBP lines, location of data holdings, and media used. Four surveys within the Vlaming Sub-Basin / Mentelle Basin have associated bottom profiler data (Table 3.1 and Figure 3.6).

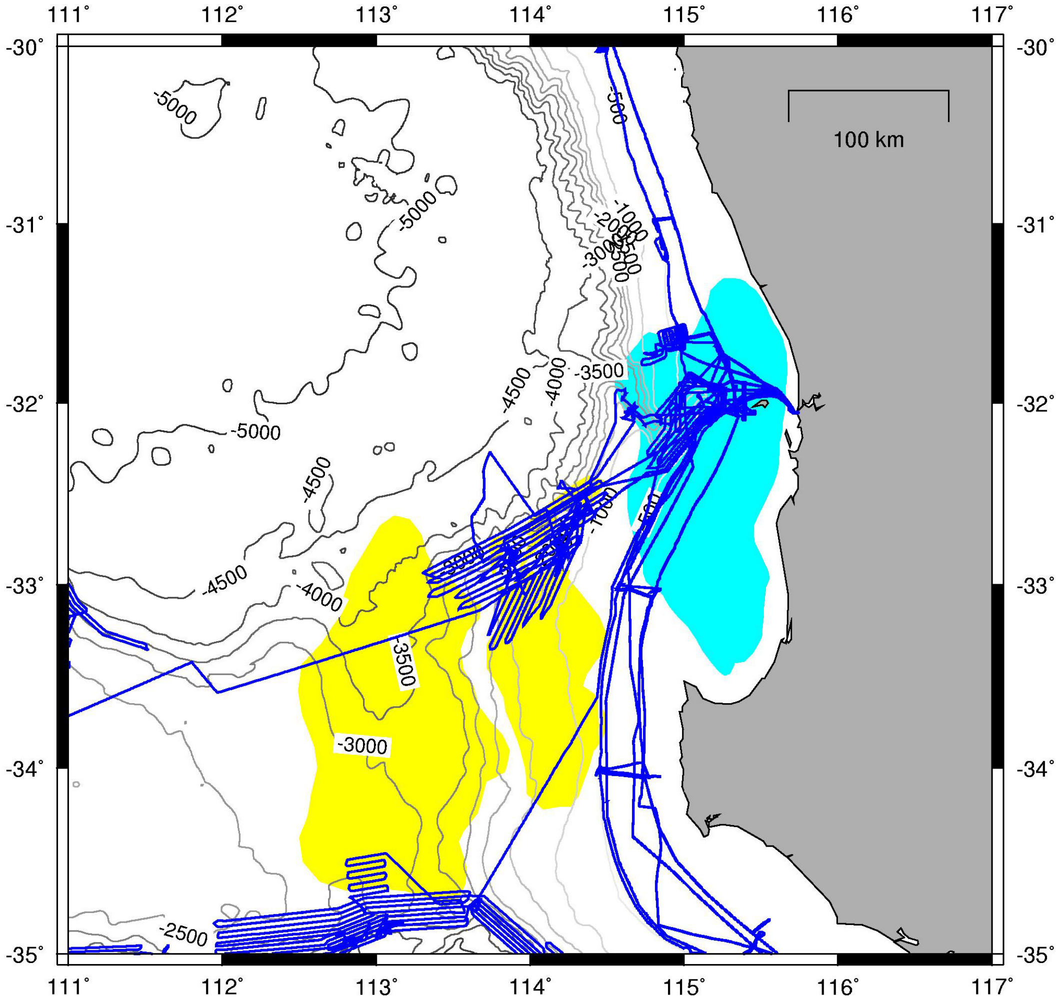


Figure 3.6: *Track map of surveys within the Vlaming Sub-Basin / Mentelle Basin that have sub bottom profiler data associated with them.*

While sub-bottom profiler data can be of limited use for habitat mapping it is also useful for understanding seabed structures. Within the Mentelle/ Vlaming Sub-Basins, bottom profiles have been used to identify sedimentary structures, fluid escape and/or diagenesis (Heap et al., 2006).

On the continental slope, the seabed reflector forms a distinct (typically less than 1 ms) smooth surface gently dipping to the north-west, towards the head of the Perth Canyon. Several semi-parallel subsurface reflections can be traced regionally, although their strength, continuity and depth are variable across the area. These sub-bottom reflections converge at several small tributaries of the Perth Canyon, where they form sediment drapes and levees (Figure 3.7).

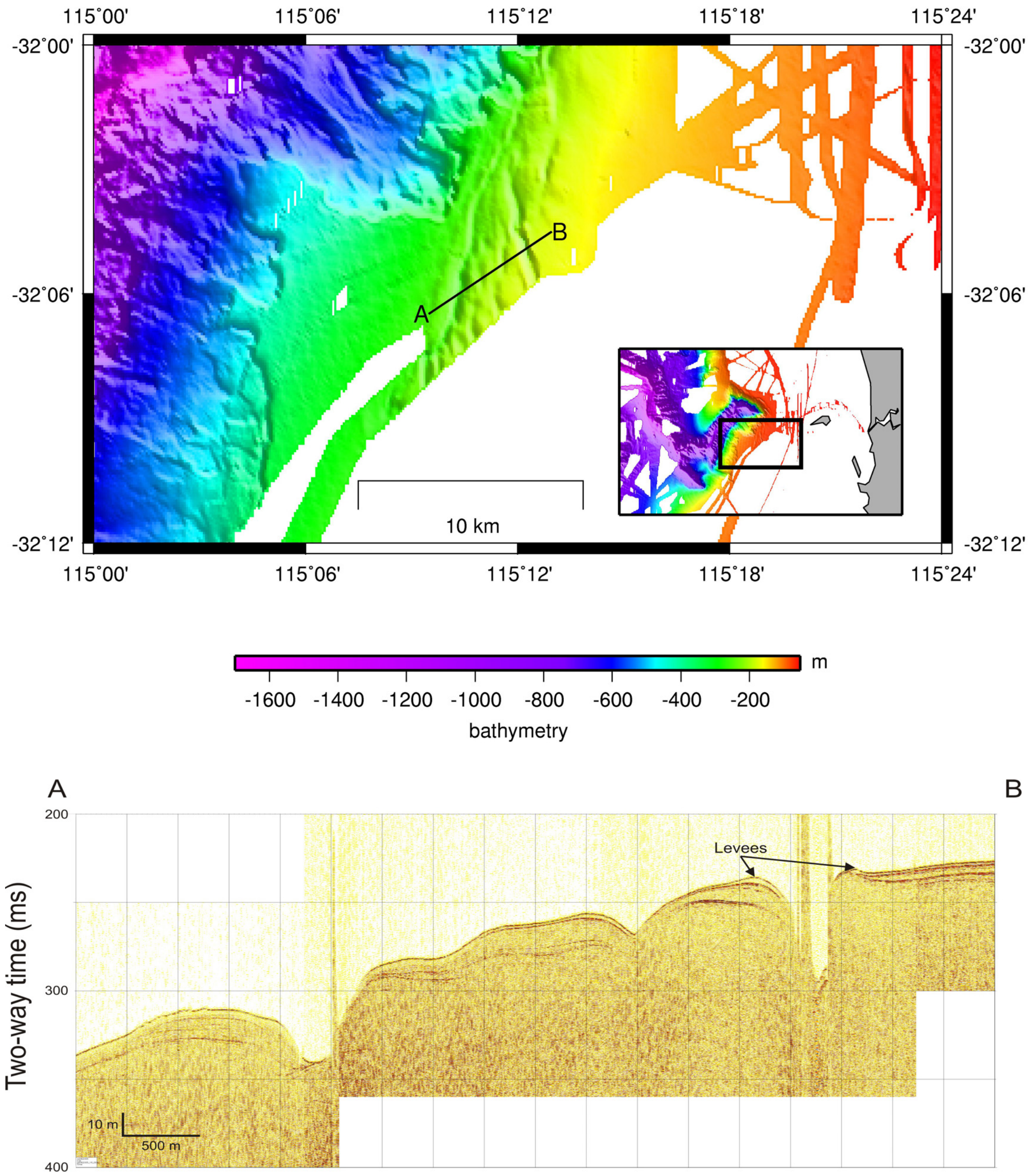


Figure 3.7: *Multi-beam (swath) sonar bathymetry (top) and sub-bottom profile (bottom) of several small tributaries of the Perth Canyon.*

Small depressions and prominences occur intermittently on the seabed between the Perth and Busselton Canyons (Figure 3.8). These surface irregularities are visible on the swath bathymetry and appear as clusters of small circular features, around 80 to 100 m in diameter. Directly beneath the surface features, doming and/or disruption of the shallow sub-bottom reflectors occurs. These features may be fluid escape features (pockmarks) or may be associated with some digenetic process.

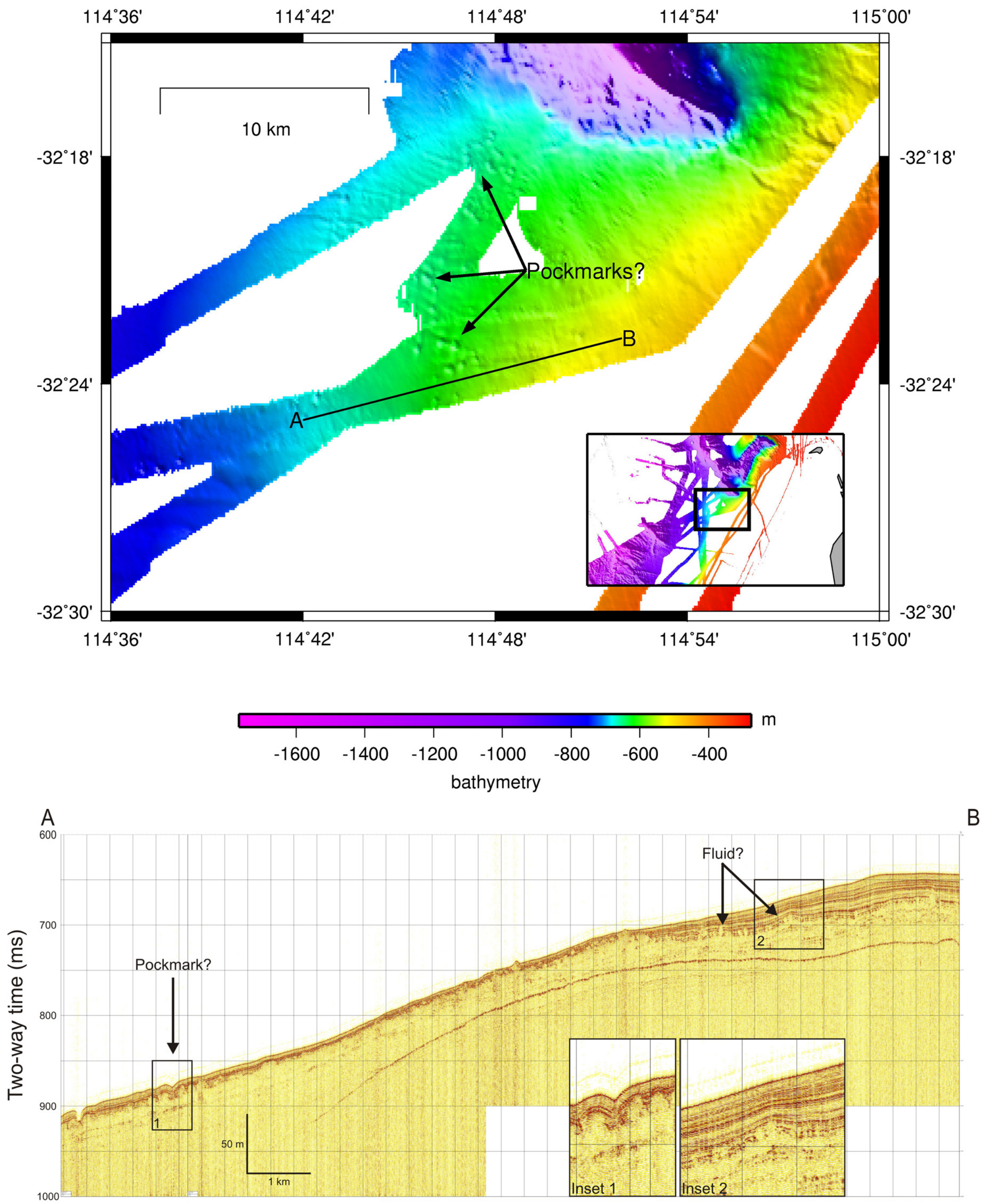


***Figure 3.8:** Multi-beam (swath) sonar bathymetry (top) and sub-bottom profile (bottom) across a series of surface irregularities that may be caused by fluid escape (pockmarks) or may be digenetic features.*

3.5 SUMMARY

Multibeam bathymetry data covers large portion of the Vlaming Sub-Basin / Mentelle Basin with data well distributed between the shelf, slope and deep sea. Coverage of acoustic reflectivity and sub-bottom profiler is more limited (Table 3.3) and restricted to detailed geological surveys such as Heap et al. (2008). All datasets are publicly available through Geoscience Australia for further processing and inspection by external clients.

Table 3.3: Summary of marine geophysical datasets available in the Vlaming Sub-Basin / Mentelle Basin region. No coverage area is supplied for sub-bottom profiler as only profile information is acquired

Data types	Coverage Area (km^2)	Survey data (kilometres)
Bathymetry	5.8×10^5	36000
Acoustic Reflectivity	4.8×10^5	30000
Sub-bottom profiler	-	14500

4. Geomorphology

4.1 INTRODUCTION AND DATA SOURCES

Early marine geological studies offshore from southwest Western Australia focused on surface sediments of the continental shelf (Carrigy & Fairbridge, 1954; Collins, 1988), aspects of select submarine canyons (Von der Borch, 1968; Exon et al., 2005), modern shelf carbonate sediments (James et al., 1999) and the large scale structure of the Naturaliste Plateau (Borissova, 2002). Where relevant, results from these prior studies are summarised here. At the regional scale, information on the general geomorphology for these areas is based on the 250 m bathymetric grid and prior descriptions of the western Australian continental margin provided in Harris et al. (2005) and Richardson et al. (2005). These studies show that the Vlaming Sub-Basin encompasses shelf, reef, slope and canyon geomorphic environments, whereas the Mentelle Basin extends into deeper water and incorporates terrace, slope, canyon, trough and plateau environments (Figure 4.1).

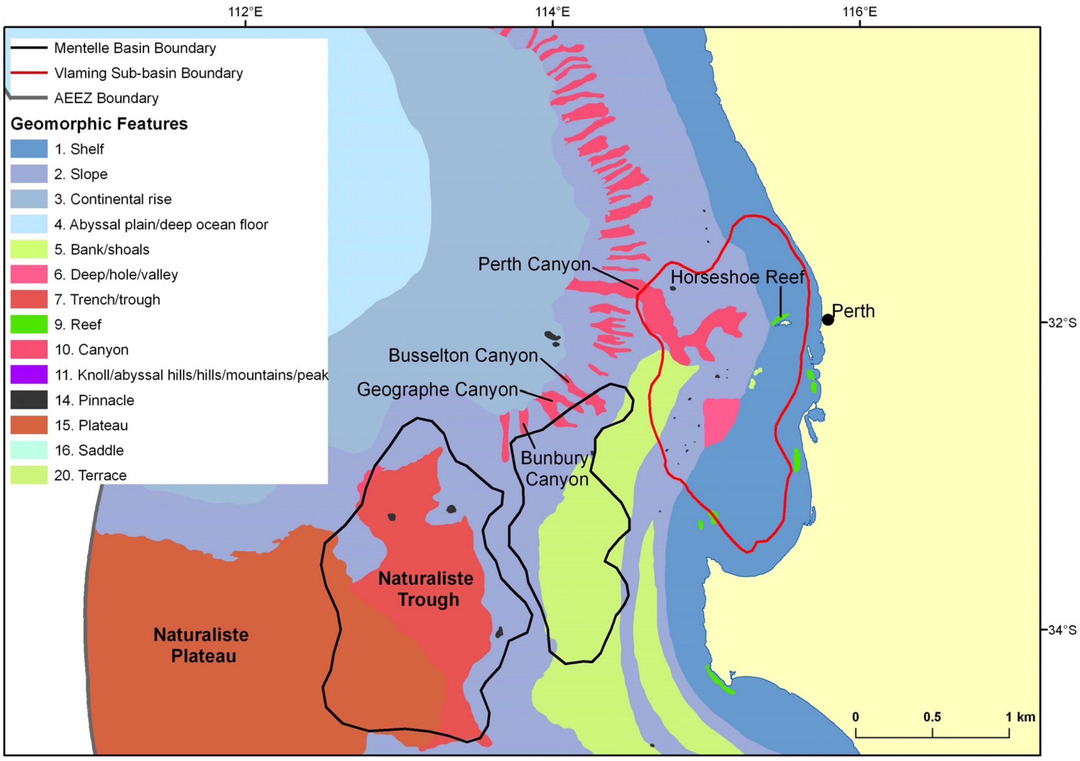


Figure 4.1: *Geomorphic features map of the continental margin of southern Western Australia showing extents of the Vlaming Sub-Basin and the Mentelle Basin (modified from Harris et al. 2005).*

The key information sources for this summary are data and post-survey reports from three marine surveys carried out by the Australian Geological Survey Organisation (AGSO) and Geoscience Australia (GA). These surveys focused on the deeper water areas of the outer shelf and slope. The first of these surveys was carried out in 1988, involving a seismic mapping and sampling survey of the Vlaming Sub-Basin on the RV *Rig Seismic* (BMR Surveys 80/81; Marshall et al., 1993). The second and third surveys (GA SS07/2005 and SS08/2005), were undertaken in 2005 on the RV *Southern Surveyor* (Heap et al. 2008). The latter survey was the more comprehensive and included high resolution seabed mapping using multibeam sonar and sediment sampling within a 6480 km^2 area of the northern portion of eastern depocentre of the Mentelle Basin, extending onto the adjacent Yallingup Shelf and the Vlaming Sub-Basin. However, the surficial morphology and sediments of the central and southern portions of the eastern Mentelle Basin, and the entire western Mentelle Basin remain poorly documented.

4.2 VLAMING SUB-BASIN

4.2.1 General Characteristics

The Vlaming Sub-Basin partly underlies the continental shelf, locally known as the Rottnest Shelf (Carrigy and Fairbridge, 1954) and extends to the upper continental slope, spanning water depths from 0 m to 3,000 m (Figure 4.2). The width of the Rottnest Shelf increases to the south from 43 km offshore from Perth to 93 km offshore from Bunbury, with the shelf break located at an average water depth of 170 m (Collins, 1988). On the basis of a regional gradient change, the shelf divides into a flat (0.05-0.2^o) inner shelf plain, spanning 0 m to 100 m water depth and a steeper (0.3-0.45^o) outer shelf that ends at the shelf break.

The morphology of the inner shelf is characterised by four coast-parallel zones defined on the basis of navy depth soundings, as follows: (i) a gently sloping platform in 0-20 m water depth with local shallow depressions, irregular limestone ridges, reefs (e.g. Bouvard Reefs; Semeniuk, 1996) and islands; (ii) a smooth, low gradient plain from 20 m to 48 m depth; (iii) discontinuous, coast-parallel ridges of jagged rock up to 15 m high in 48 m to 60 m water depth, and; (iv) a zone of irregular rock outcrop on a locally steeper surface (~0.4-0.6°) between 60 m and 100 m depth (Collins, 1988). The outer edge of this zone is flanked by a continuous terrace in water depth of 86-98 m.

The outer shelf is 11-17 km wide and has a generally smooth morphology with minor local relief of 1-2 m (Collins, 1988). The gentle seaward gradient of the outer shelf (0.3-0.45^o) is interrupted by a near-flat terrace at 150-170 m water depth. The terrace is 1 km wide and described by Collins (1988) as “incised into the outer shelf.” Beyond the shelf break, at 170 m, the upper continental slope extends basinward as a smooth, steep surface, ranging in gradient from ~3° to ~5° (Figure 4.2). Within the northern half of the Vlaming Sub-Basin , the mid- to lower continental slope is incised by several canyons, the largest of which, Perth Canyon, has been fully mapped using multibeam sonar and is described below.

4.2.2 Perth Canyon

The dominant geomorphic feature of the Vlaming Sub-Basin is the Perth Canyon. The canyon extends approximately 120 km from the upper continental slope to the abyssal plain (Figures. 4.2, 4.3). The canyon head is located in 170 m water depth at the shelf break but it has not incised into the outer shelf. Maximum valley depth is about 2000 m below the adjacent slope. The form of the canyon is described in detail by Heap et al. (2008), with the main characteristics being a semi-meandering channel form, down-valley widening from <100 m at the head to 6-8 km in the lower reaches, two well defined tributaries that strike to the south and steep valley walls (10° to 40°) formed in exposed bedrock. The mouth of the canyon is located in about 4500 m water depth where it grades onto the abyssal plain.

High resolution multibeam bathymetry data collected from the Perth Canyon and the surrounding slope by RV *Southern Surveyor* reveals evidence for active sediment transport from the continental shelf and slope into the canyon (Figure 4.4). In particular, a series of slumps are imaged for the area to the east and south of the canyon headwall in about 170 m water depth. The orientation of these slumps (north to northwest alignment) indicates movement of material toward the canyon. Slumps and scarps are also mapped across the slopes and walls that feed into the canyon (Figure 4.4). These features are especially clear on slope and walls around the main canyon head and tributaries, indicating that slope wasting and canyon incision is an ongoing process.

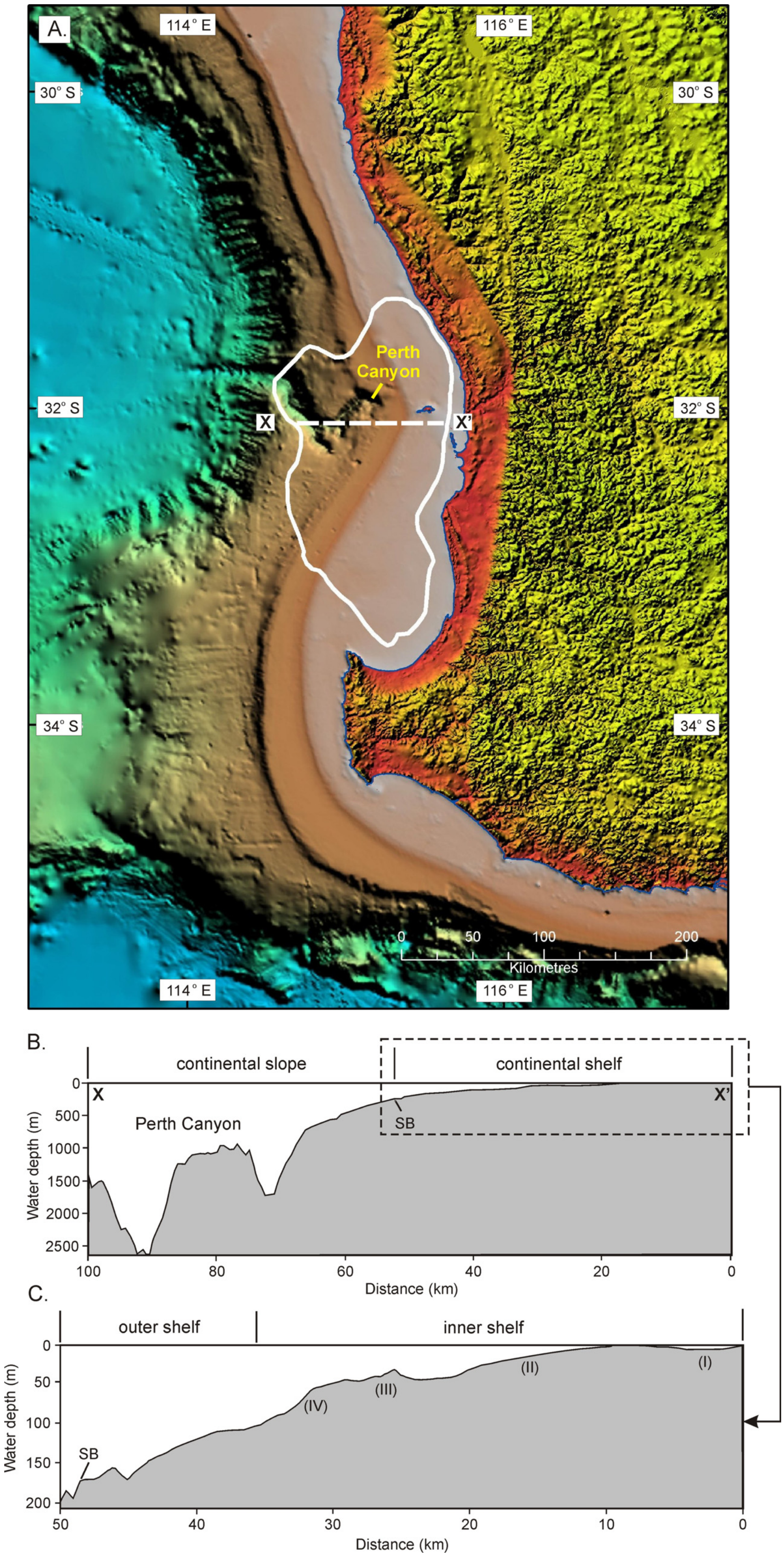


Figure 4.2: *(A) Map of southwest margin of Australia showing the extent of the Vlaming Sub-Basin and location of bathymetric cross-section X-X'; (B) Bathymetric profile of the continental shelf and slope; (C) Bathymetric profile of the inner shelf to outer shelf, showing sediment zones (i) to (iv) described in the text. SB denotes the shelf break.*

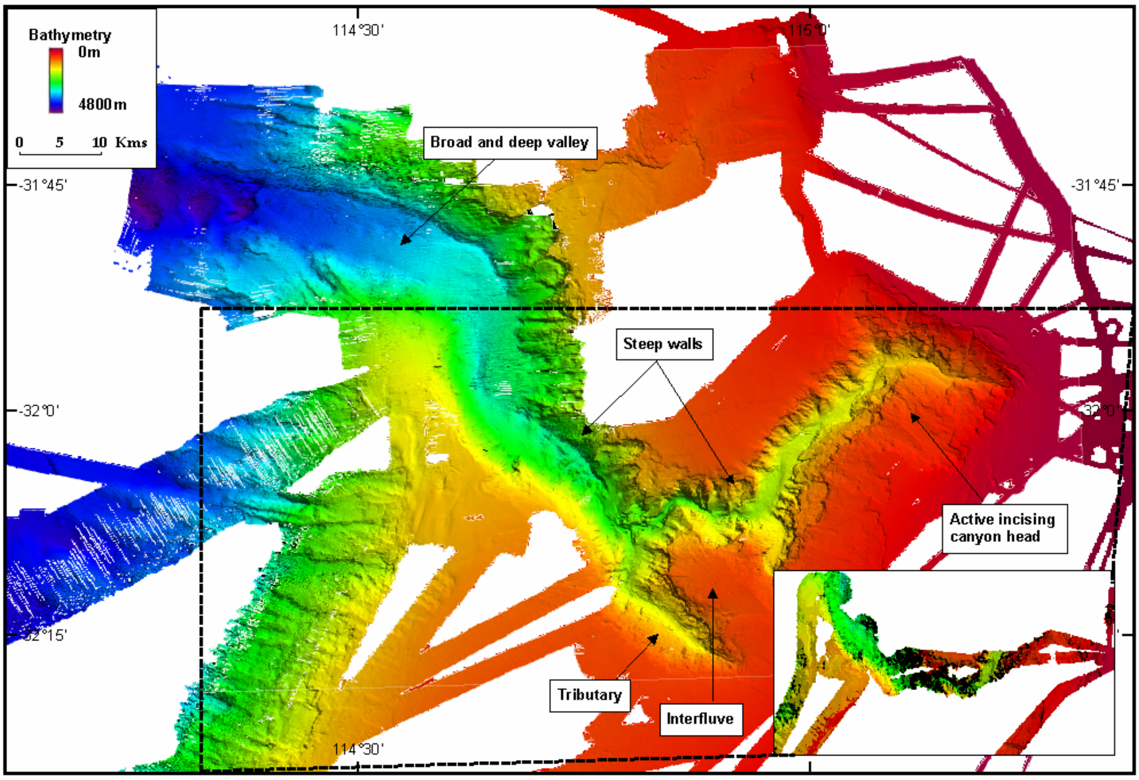


Figure 4.3: *Multibeam sonar image of Perth Canyon.*

Shallow seismic mapping of the Perth Canyon provides additional information on seabed geomorphology for the outer continental shelf and slope of the Vlaming Sub-Basin (Table 4.1). For the outer shelf, seismic data show a seabed reflector that varies from smooth to rough and few sub-bottom reflectors, indicative of a hard bottom with local outcrops of rocky reef. In contrast, the upper continental slope is seismically imaged as a continuous sediment cover in the vicinity of the Perth Canyon, including levee-like deposits alongside the tributaries to the canyon. Where seismic data quality is best, such as on the upper slope to the south of Perth Canyon, the sediment cover is interpreted to be up to 38 m thick (Heap et al. 2008). This thickness decreases to ~25 m on the mid slope alongside the lower reaches of the Perth Canyon. Within the canyon and its tributaries, seismic data show additional evidence for geological activity, notably slumping of large sedimentary blocks into the canyon from the upper continental slope (Figure 4.5).

To the south of the Perth Canyon, the upper continental slope is characterised by a smooth, gently sloping surface that extends from 170 m to 1,110-1,500 m water depth. Locally, the slope is characterised by small depressions, knolls and shallow channels. In contrast, the lower continental slope is steeper (~3°-5°) and rougher, with evidence for slumping and more extensive local channelling in the area to the southwest of the Perth Canyon (Heap et al., 2008).

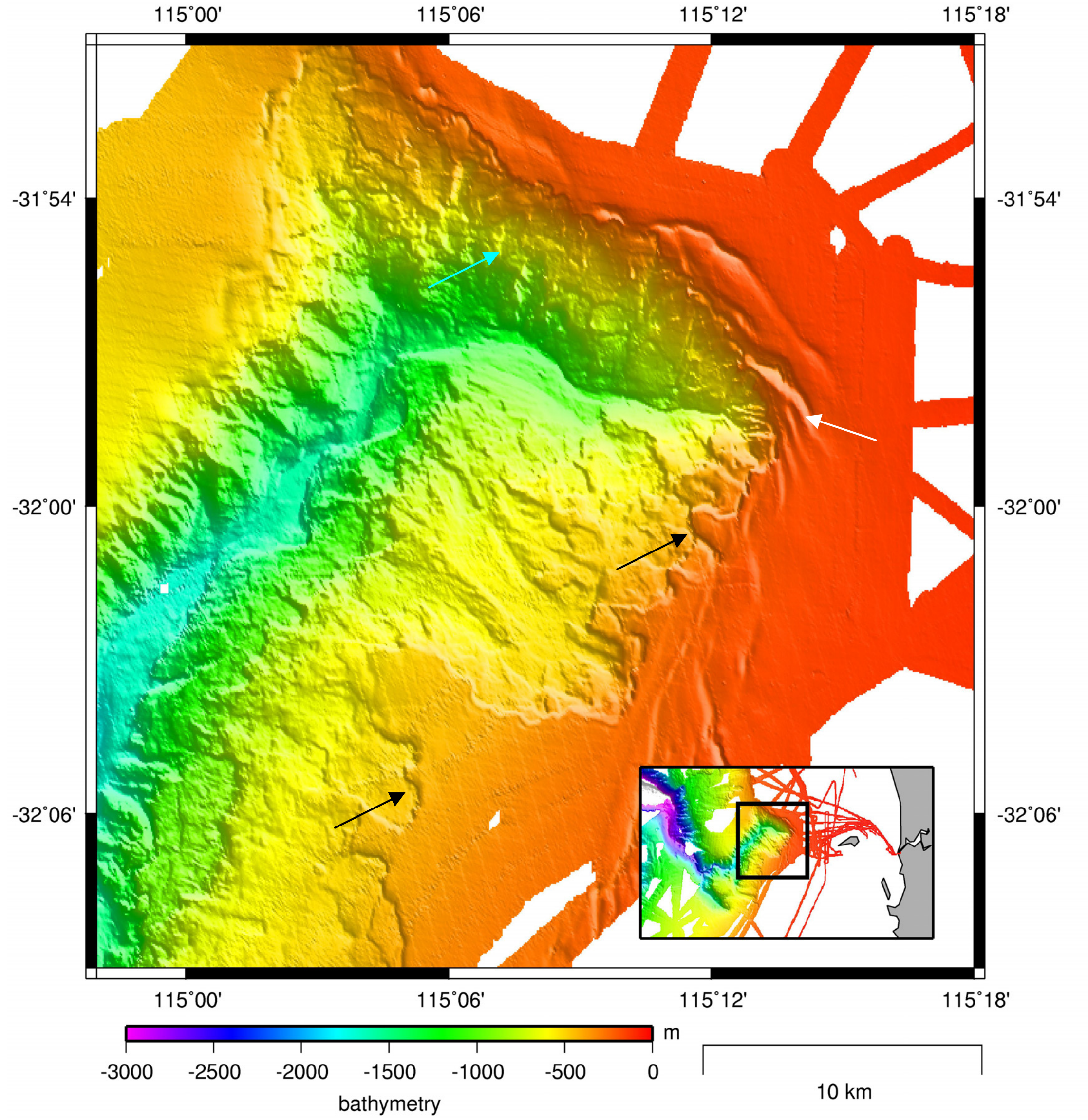
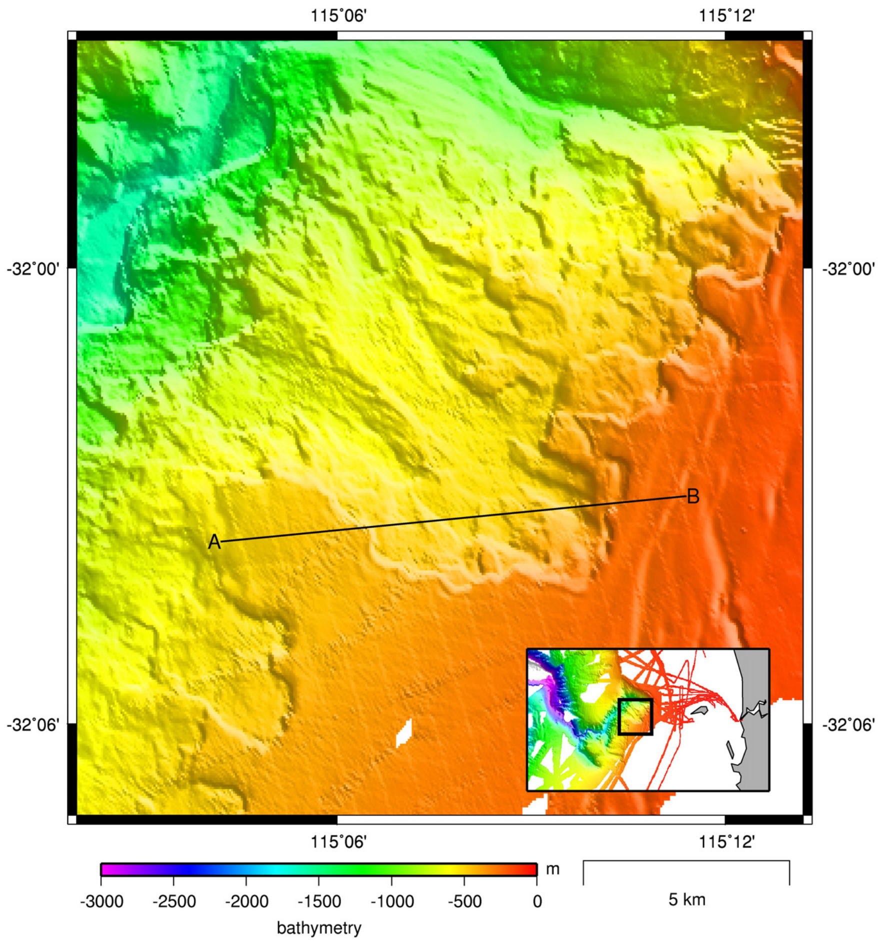


Figure 4.4: *Multibeam sonar image of the head of the Perth Canyon, showing slumps adjacent to the canyon head (white arrow), scarps (black arrows) and slumped material (blue arrow) across steep canyon walls.*

A.



B.

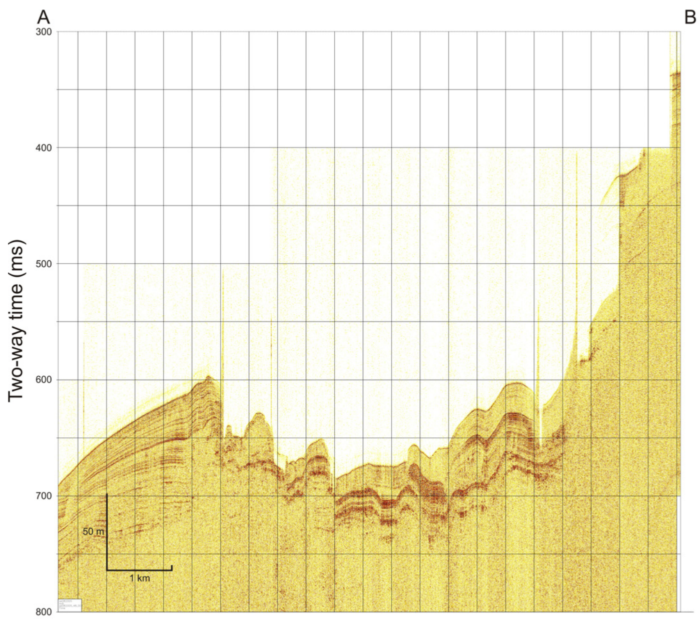
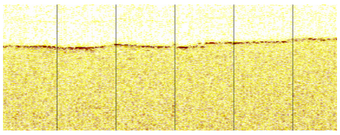
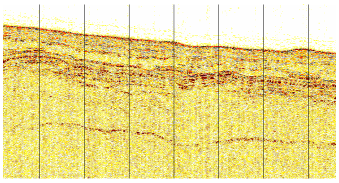
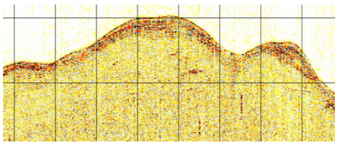
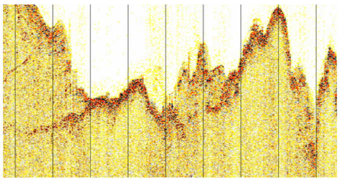
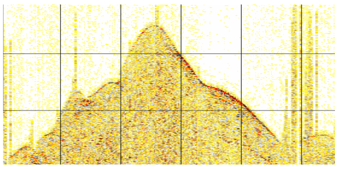
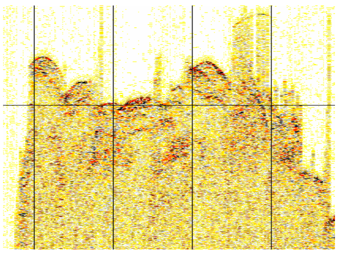
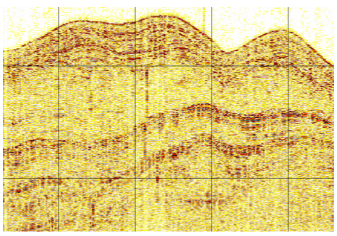


Figure 4.5: *(A) Multibeam sonar image of an area of the upper continental slope adjacent to the Perth Canyon showing scarps and slump blocks. (B) Sub-bottom profile across a slumped section of the upper slope along line A-B shown in the sonar image.*

Table 4.1: Representative sub-bottom profiles for different geomorphic environments of the Vlaming Sub-Basin (modified from Heap et al. 2008).

Example	Description	Geomorphic environment
	Distinct and continuous sea floor reflector with no sub-bottom reflectors.	Outer continental shelf.
	Distinct and continuous sea floor reflector with continuous parallel sub-bottom reflectors.	Thick sediments on the upper and mid slope.
	Distinct and continuous sea floor reflector with distinct and continuous but converging (non-conformable) sub-bottom reflectors.	Areas on the mid slope with thin sediment cover; often draped.
	Strong sea floor reflector with no clear sub-bottom reflectors.	Canyon floors and areas of rock outcrop on the mid slope.
	Large, overlapping and single hyperbolic reflectors of the sea floor. Sub-bottom reflectors faint to absent.	Localised areas on the lower slope with irregular morphology.
	Overlapping hyperbolic reflectors of the sea floor. Sub-bottom reflectors discontinuous.	Areas of steep morphology such as canyon walls and rugged areas on the lower slope with little sediment cover.
	Distinct and continuous sea floor reflector with two discrete (unconformable) sub-bottom reflection packages. Both packages are defined by multiple, continuous, parallel reflections.	Mid slope between the Geographe and Bunbury Canyons, intersected by narrow, linear channels

4.3 MENTELLE BASIN

4.3.1 General characteristics

The Mentelle Basin is located to the southwest of the Vlaming Sub-Basin in 500 to 3300 m water depth. It forms most of the Naturaliste Trough and is bordered to the east by the Yallingup Shelf and to the west by the Naturaliste Plateau. The Mentelle Basin comprises eastern and western depocentres with respective areas of 19,000 km^2 and 17,400 km^2 (Figure 4.6) (Bradshaw et al., 2003). The eastern Mentelle basin incorporates part of a large regional terrace on the continental slope of the southwest margin plus the lower continental slope and the upper reaches of several canyons (Figures. 4.1, 4.6). The western Mentelle basin includes the Naturaliste trough and adjacent plateau. In addition, two pinnacles are interpreted from low resolution bathymetry by Harris et al. (2005) at the foot of the continental slope on the boundary of the two depocentres and a third in the Naturaliste trough. However, the geomorphic detail of these particular features and surrounding submarine terrain remains poorly documented.

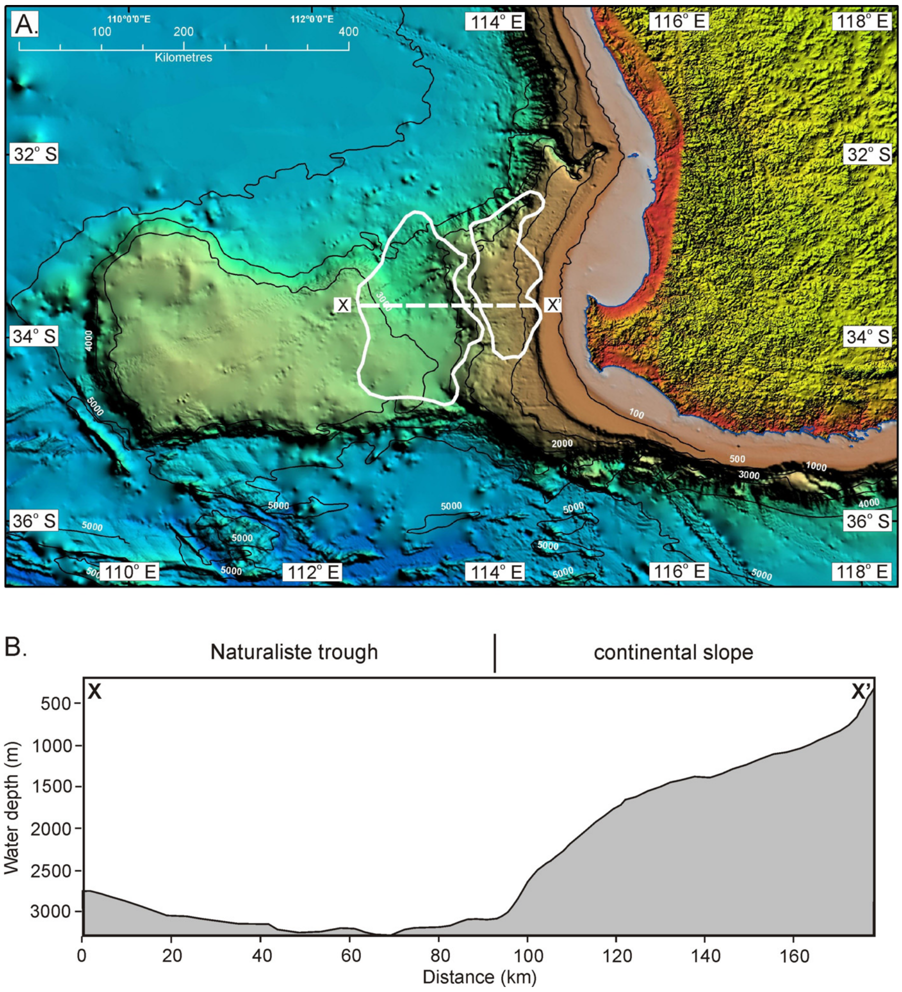


Figure 4.6: *(A) General bathymetry of the Mentelle Basin showing the location of cross-section X-X'; (B) Bathymetric profile across the Mentelle Basin, showing the lower continental slope and the Naturaliste trough.*

4.3.2 Canyons

The lower continental slope forming the northern part of the eastern Mentelle basin is incised by the Geographe, Busselton and Bunbury Canyons (Figure 4.7). Each of these was mapped during the 2005 Geoscience Australia survey on RV *Southern Surveyor* (Figure 4.8) (Heap et al. 2008), including an unnamed canyon that lies outside the boundary to the Mentelle Basin. The heads of all four canyons are located between 1,200 m and 2,500 m water depth and have not incised into the continental shelf; as such, they are termed blind canyons (Heap et al. 2008). Each canyon extends across the boundary of the Mentelle Basin onto the continental rise. However, the geomorphology along the full length of the canyons is described here.

The mapped canyons are characterised by a relatively straight, short valley ranging in length from 25 km (Busselton Canyon & unnamed canyon) to 55 km (Bunbury Canyon). General valley form changes along these canyons from narrow (3-4 km) with steep sides (10-20°) in the upper reaches to broader (5-10 km) flatter valleys (3-6°), terminating on broad plains in water depths of 3,000 – 3,600 m (Figure 4.9). Canyon walls are typically steep with headwall gradients of up to 50° and valley depths in the range of 200 - 500 m. Busselton Canyon has developed a deeper and more complex valley, however, with a 600 m high headwall and a tributary valley that strikes to the south, plus several 100 m deep channels along the eastern sidewall (Figure 4.8).

Multibeam sonar imagery of canyons show canyon floors are generally smooth, but with local debris deposits of boulder-sized material below steeper sidewalls and scarps. In contrast, canyon sidewalls display a rugose morphology of slump mounds, ridges and scarps. This surface form is particularly well developed on the eastern sidewall of Busselton Canyon (Figure 4.10).

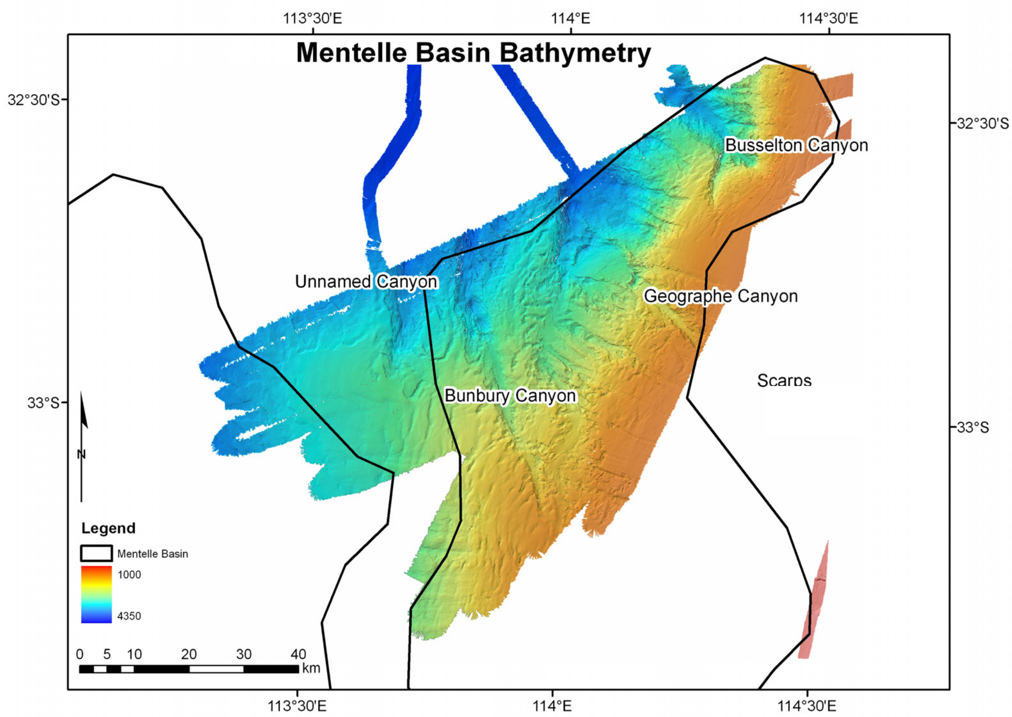


Figure 4.7: *Multibeam sonar image of the lower continental slope in the northern sector of the Mentelle Basin with canyons indicated. Colour bar scale shows water depth in metres.*

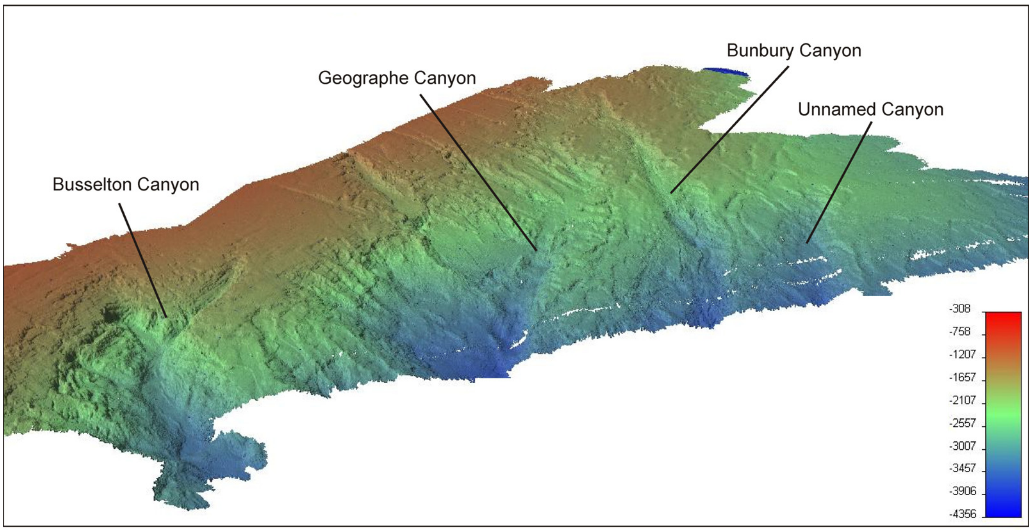


Figure 4.8: *Multibeam sonar image of the lower continental slope for northern sector of the Mentelle Basin, in perspective view looking to the southeast. Canyons are indicated. Colour bar scale shows water depth in metres.*

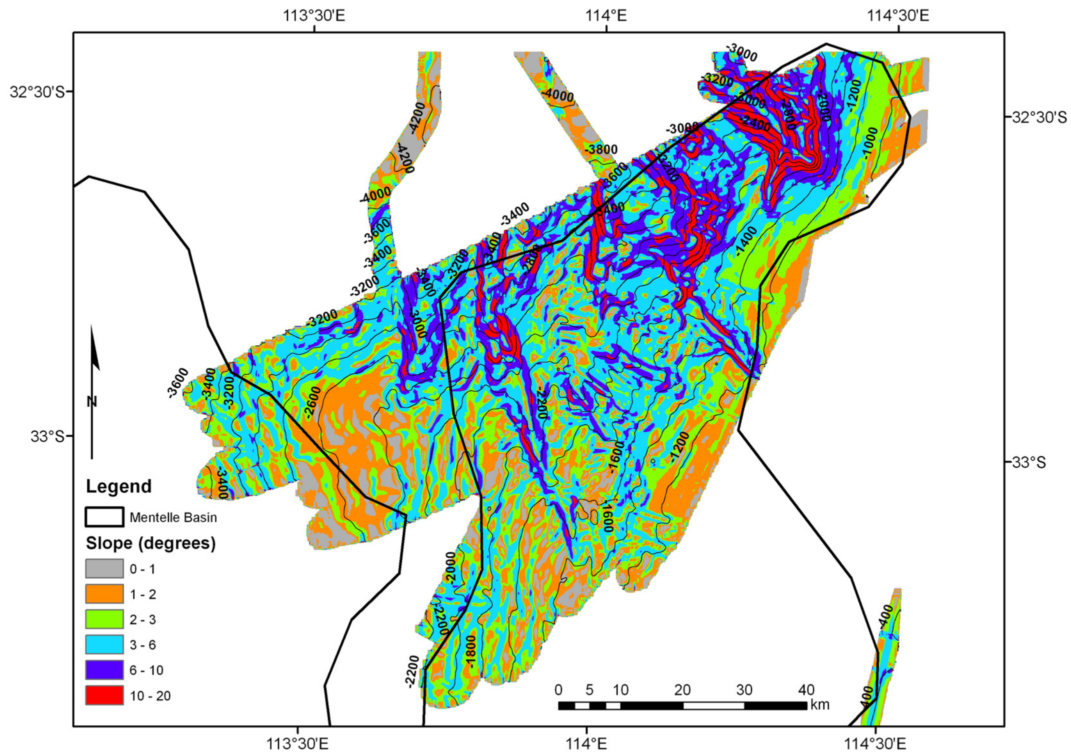


Figure 4.9: *Map of northern sector of the Mentelle Basin, showing distribution of slope classes across the lower continental slope.*

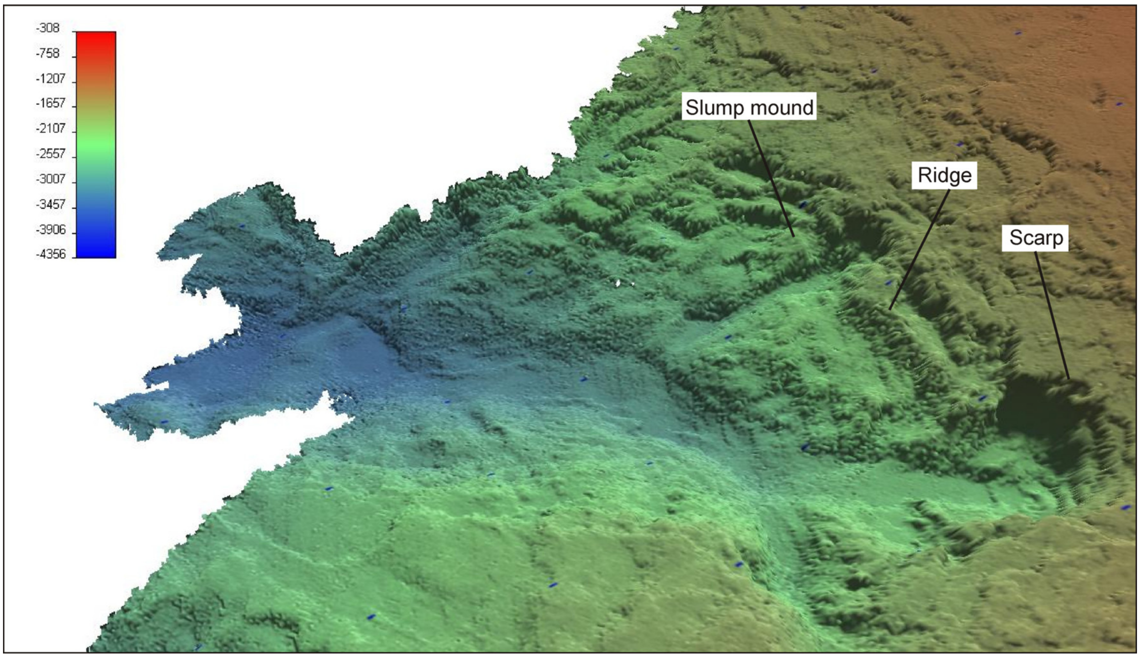


Figure 4.10: *Perspective view of Busselton Canyon, showing slump mounds, ridges and scarps along the eastern sidewall and smooth canyon floor. Colour scale shows water depth in metres.*

4.3.3 Slope Deformation & Mass Movement

Several forms of geomorphic evidence for mass movement and slope instability are recognised from multibeam sonar images and sub-bottom profiles of canyons and slopes in the eastern depocentre of the Mentelle Basin. These include localised slumps, scars, scarps, rotational slides and translational slides. Across the slope the sediment cover is continuous, but with localised pockmark depressions on the mid slope that Heap et al. (2008) interpret as sites of fluid escape. The seabed around these features appears smooth to gently undulating and becomes more so to the south, in the vicinity of Geographe Canyon where the sediment thickness is seismically imaged to ~70 m (Heap et al., 2008). Examples of small scale slumping and scarring are interpreted from undulations in swath bathymetry within a short valley to the south of Geographe Canyon in water depths of 2000 m to 2400 m (Figure 4.11). Failed material has not been transported far down the valley floor (< 1 km) and forms bathymetric highs (20-80 m) within the confines of the valley. The upper half of the valley has a smoother profile with a slope of approximately 2.5^{o}, suggesting a more stable surface. The headwall scar left by the uppermost slump has a slope of ~50^{o} and forms the steepest surface measured in Busselton Canyon by Heap et al. (2008). Overall, this morphology indicates a retrogressive style of slope failure and is likely the most widespread form of mass movement on the lower continental slope of the Mentelle Basin.

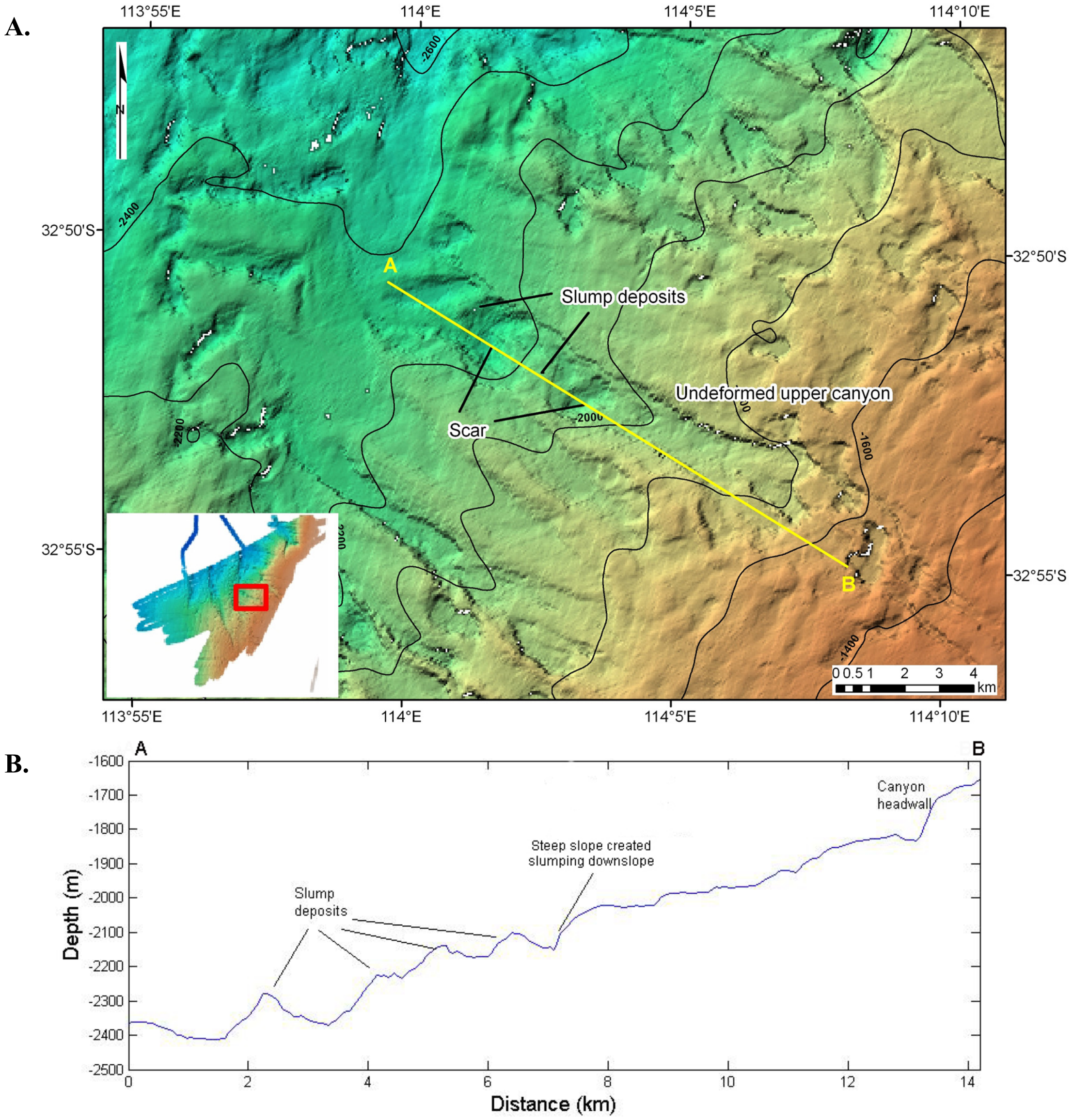


Figure 4.11: *(A) Multibeam sonar image of a short valley 10 km to the south of Geographe Canyon, with interpreted slumps and scars indicated. (B) Bathymetric profile across slumps along transect shown by line A-B on sonar image.*

A different form of localised deformation is recognised for an area on the mid-slope in water depths of 1200 m to 1400 m above Bunbury Canyon (Figure 4.12). Here the surface is characterised by small scarps, slumps and closed depressions that together produce a rugose terrain. Local relief across this area is 20-50 m, with depressions up to 100 m deep. The average gradient of the continental slope in this area is about 2^{o} and there is no evidence for large scale displacement of slump material, suggesting that deformation may be related to gradual dewatering of surface sediments possibly in association with near-surface faulting. This deformational style is not continuous along the mid-slope, however, with the area to the immediate northeast relatively undeformed (Figure 4.12).

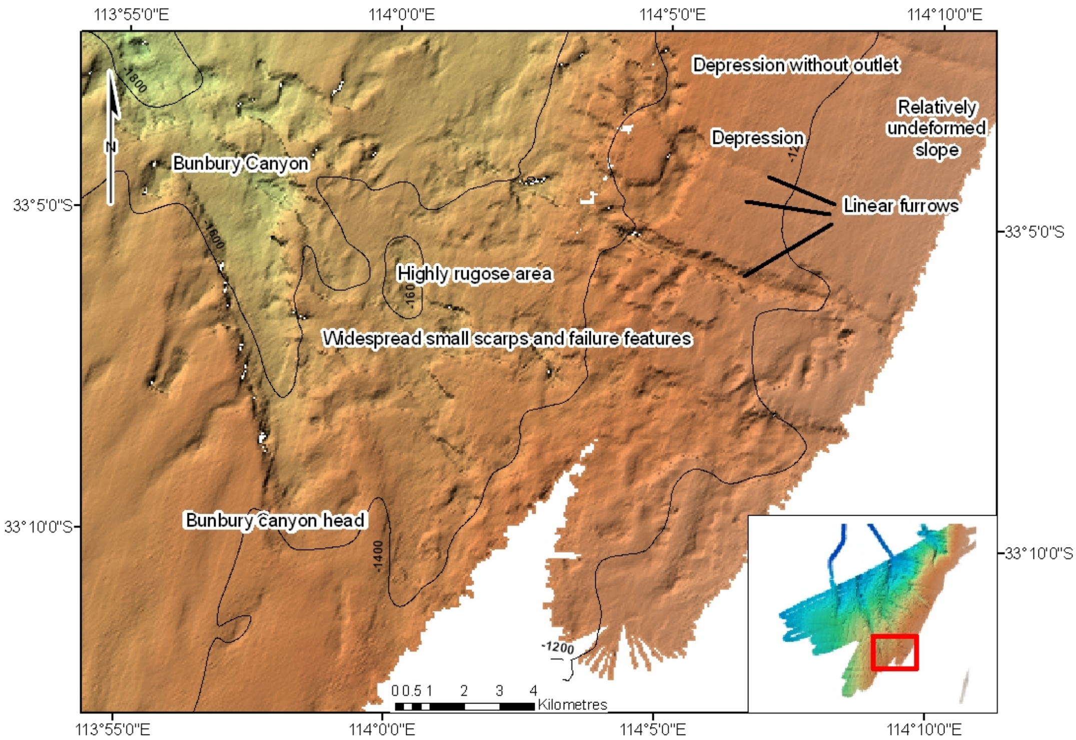


Figure 4.12: *Multibeam sonar image of an area of mid-slope to the east of Bunbury Canyon, showing widespread small-scale scarps and slumps.*

An example of a rotational slide is interpreted from sub-bottom profile data on the continental slope at the head of Busselton Canyon (Figure 4.13). Here the slide block is 1 km long on a slope of 2-3^{o} with vertical relief of less than 5-10 m. On the multibeam sonar image this terrain appears as subtle undulations that occur across the slope to the headwall of Busselton Canyon (Figure 4.14). The age and rate of mass movement in this area is unknown, but the geomorphic evidence at least illustrates an active mechanism for transfer of material from the slope into canyons.

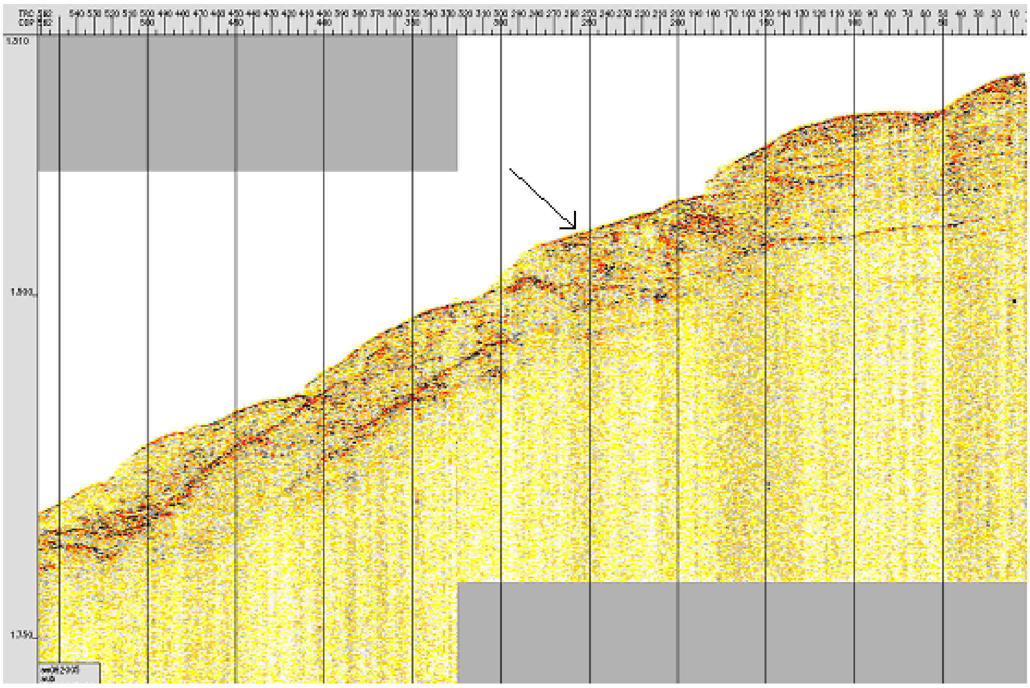


Figure 4.13: *Sub-bottom profile across the continental slope above Busselton Canyon. The arrow indicates an interpreted slump block with internal bedding that dips into the slope as evidence of rotational failure.*

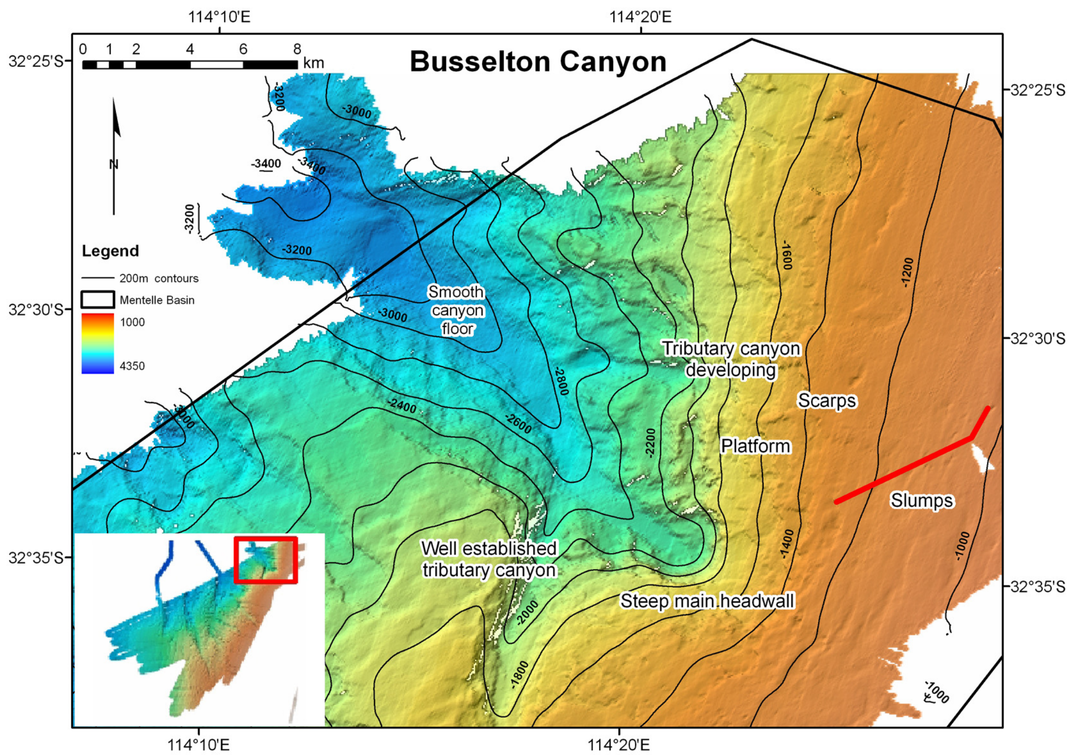


Figure 4.14: *Multibeam sonar image of Busselton Canyon with geomorphic features indicated. Red line indicates the location of the sub-bottom profile line shown in Figure 4.13. Contour interval is 200 m.*

The largest mass movement feature in the mapped area of eastern depocentre of the Mentelle Basin is a 60 km^2 block that forms part of the Geographe Canyon floor (Figure 4.15). Swath imagery shows the block has detached and moved approximately 1500 m downslope as a translational slide. This distance is based on the width of the 300 m deep gap between the canyon floor and the upper edge of the block. The toe of the detached block is buried by a ridge of sediment which the block appears to have pushed beneath. Based on the 300 m depth of the detachment scar, the estimated volume of the slide is 18 km^3.

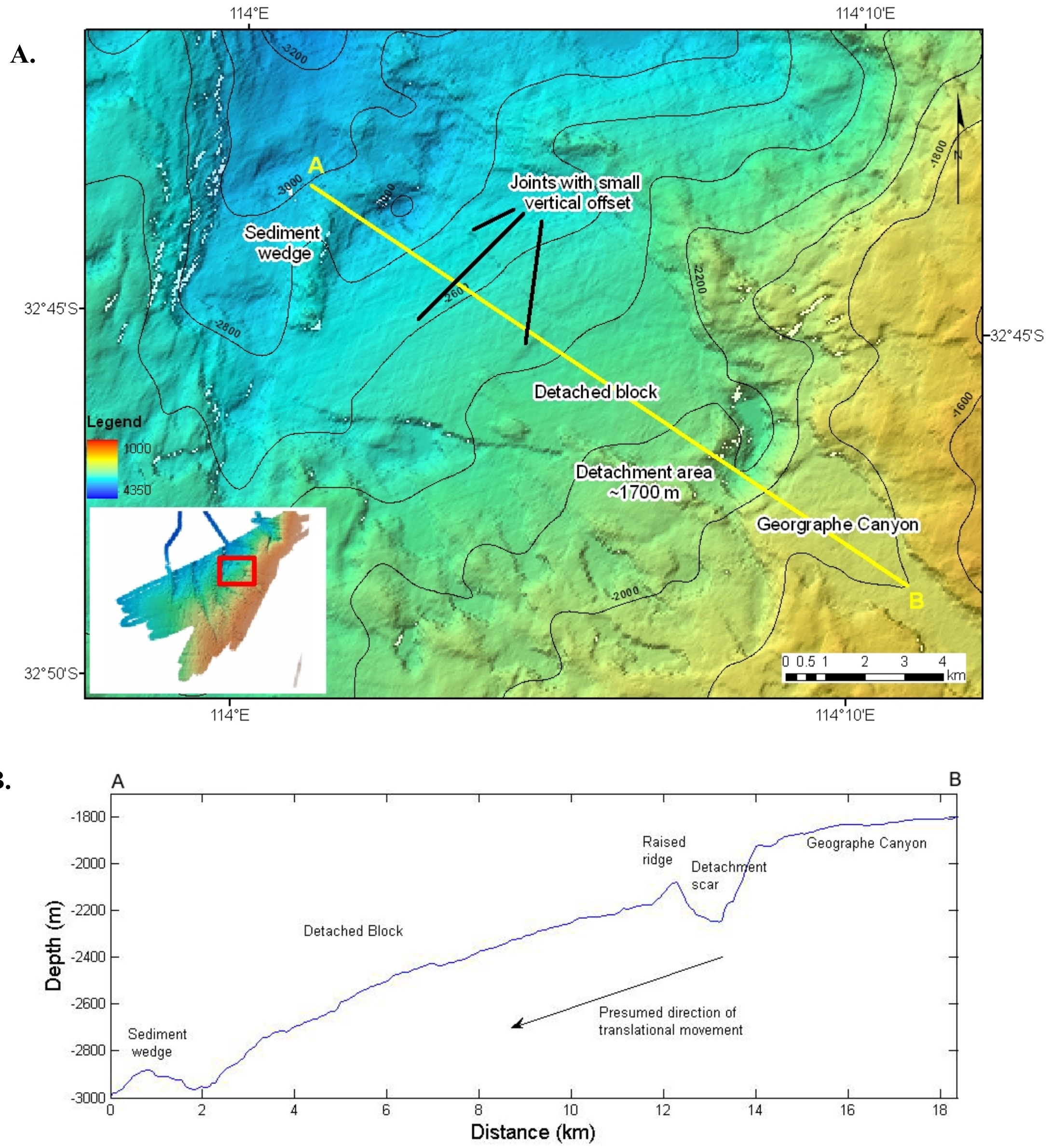


Figure 4.15: *(A) Multibeam sonar image of lower reaches of Geographe Canyon showing a large detached block. Contour interval is 200 m. (B) Bathymetric profile across the detached block. The location of the profile is shown by line A-B on the sonar image.*

In addition to large scale mass movements, the continental slope in the eastern Mentelle Basin is modified by parallel linear troughs that strike directly downslope in water depths of 1100 m to 1800 m across a gradient of ~2^{o} (Figure 4.16). The upper reaches of troughs are 100-500 m wide and 10-100 m deep. Some troughs widen to join canyon tributaries at depths >1800 m, while others maintain a near-constant width and strike to connect into canyons. The parallel and linear geometry of troughs suggests structural control. However, their downslope orientation, suggests slope processes may also be important in their formation. Regardless of their origin, it is possible that the troughs are conduits for downslope sediment transport (e.g. turbidity currents) into canyons.

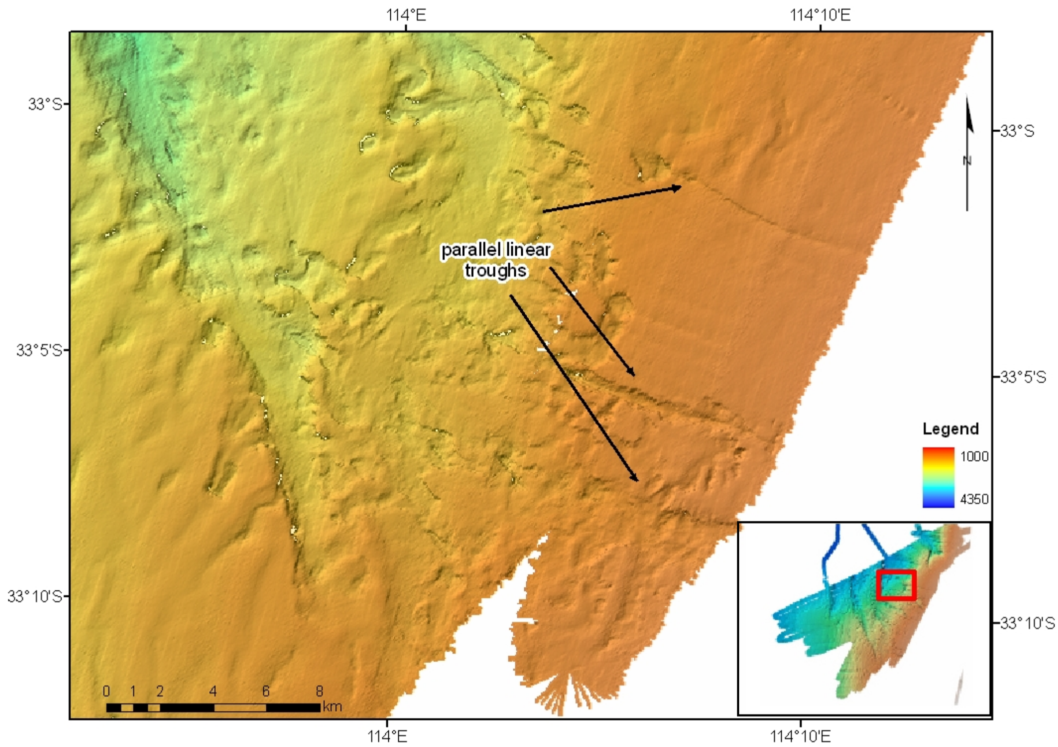


Figure 4.16: *Multibeam sonar image of the lower continental slope of the eastern Mentelle Basin, showing parallel linear troughs (indicated by arrows). The north-west trending valley is the upper end of Bunbury Canyon.*

In contrast with downslope trough incision, large areas of the lower continental slope in the Mentelle Basin are deformed by cracks that extend along the slope. This morphology is particularly well developed on the interfluve to the southwest of Bunbury Canyon (Figure 4.17). In this area, cracks are up to 100 m deep, 500 m wide and up to 15 km long. In profile, the overall slope of ~2^{o} is preserved between the cracks, apart from incipient depressions. Significant downslope transport of material is not observed, thus the formation of the cracks from an undeformed slope must result from another process. Because the cracks strike across slope with little deformation between them, they are interpreted as tension cracks caused by gravitation stress. Possible mechanisms for their initiation include dewatering and subsequent compaction of sediments and/or extensional forces such as rifting and thermal doming. The length of the features suggests that once a weakness is established and separation occurs, the crack can propagate across slope. Once formed, currents following slope contours would potentially maintain and deepen these bathymetric lows.

In summary, the mapped area of the Mentelle Basin exhibits a variety of mass movement features with the style of slope failure related to local gradient. Thus, tension cracks occur where slope is about 2°, slumps and slides are formed where slope exceeds 2°, whereas block detachment has occurred on slopes steeper than 6°. Surfaces with a gradient shallower than 2^{o} appear relatively undeformed. All forms of mass movement are localised, however, with no evidence for large scale transport of material. Accordingly, where both an erosional scar and displaced material are observed, the distance moved is less than the length of the moved material (e.g. the large detached block in Geographe Canyon is displaced ~20% of its length). Many deformation features are probably related to fluid escape, with loading causing over-pressurising of pore fluids which escape through weaknesses in overlying material.

A.

B.

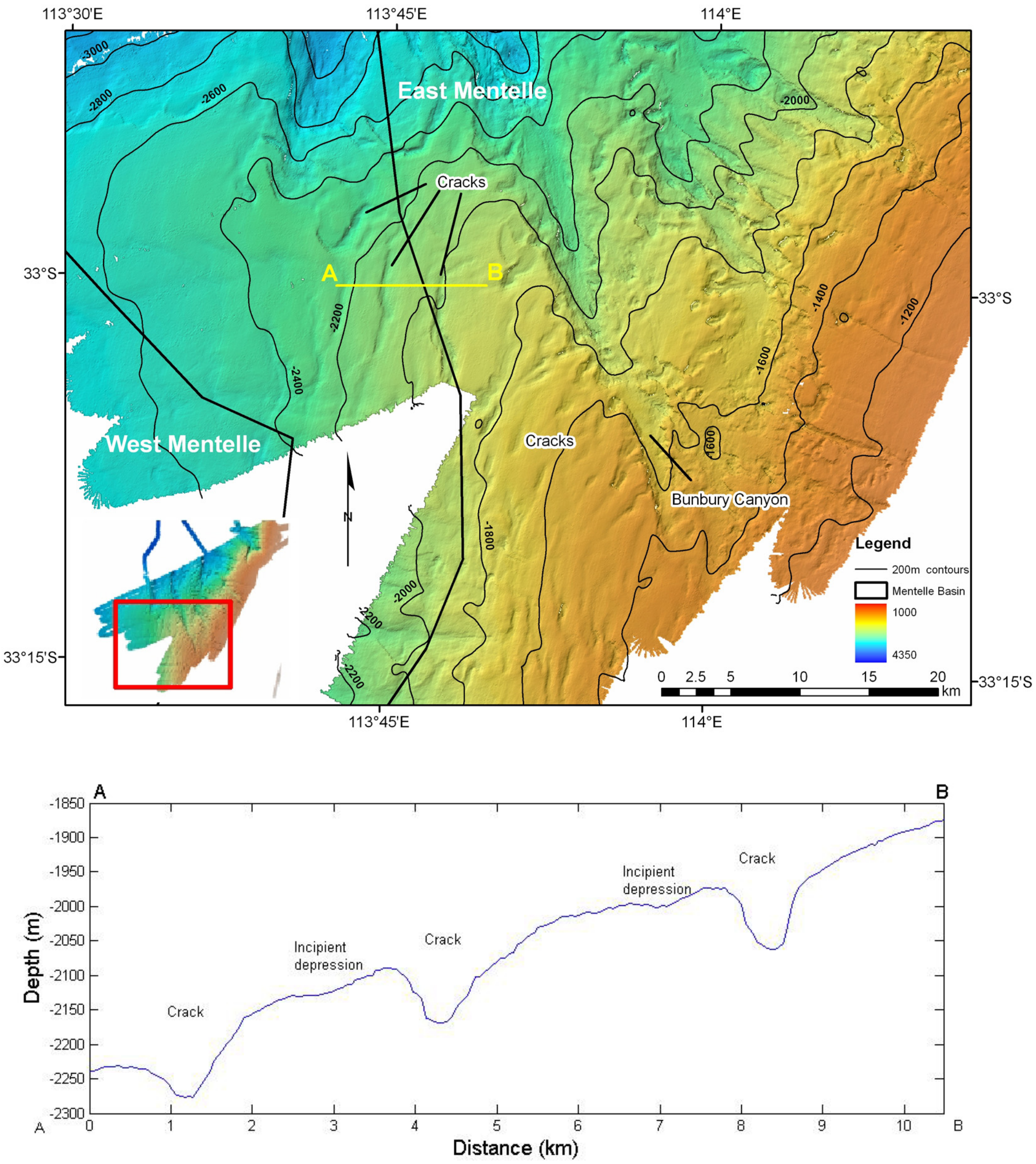


Figure 4.17: *(A) Multibeam sonar image of the lower continental slope of the eastern Mentelle Basin, showing cracks that trend along the slope. The north-west trending valley is Bunbury Canyon. (B) Bathymetric profile for line A-B*

shown on the sonar image, showing tension cracks and incipient depressions on an otherwise constant slope.

4.4 SUMMARY

The Vlaming Sub-Basin incorporates a range of geomorphic features by virtue of the fact that the sub-basin extends from the coast to the lower continental slope. For the shelf component of the Vlaming Sub-Basin, the overall geomorphic form is a low gradient, smooth surface with localised topographic highs at limestone ridges, and a distally steepened profile. Across the continental slope, the main geomorphic feature is the Perth Canyon and its tributaries. Smaller canyons also cut into the mid- to lower slope, but these features remain poorly documented. Likewise, large tracts of the Mentelle Basin have yet to be mapped in detail, including the Naturaliste Trough and Plateau. It is likely, however, that these areas are characterised by low relief terrain with the exception of a few isolated pinnacles. The greatest geomorphic complexity within the Mentelle Basin is across the mid- to lower continental slope, as shown by the recently mapped northern area of the basin. This new data clearly shows a variety of mass movement features in and around canyons, indicating a long history of slope failure.

5. Sediments

5.1 INTRODUCTION AND DATA SOURCES

Information presented here on the texture and composition of seafloor sediments of the Vlaming Sub-Basin and the Mentelle Basin is derived from 99 sample entries in the MARS database held by Geoscience Australia (Appendix 1). These samples also form part of the regional interpolation of seabed sediment types of the southwest planning region, available separately in Potter et al. (2006).

5.2 VLAMING SUB-BASIN

5.2.1 General Characteristics

Surface sediments within the Vlaming Sub-Basin are dominated by carbonate material, due to negligible supply of terrigenous sediment from rivers to the coast and shelf (Collins, 1988). Sand is the most common sediment type across the shelf, with local concentrations of gravel found in the vicinity of reefs and ridges, whereas mud dominates the sediment cover on the upper slope and in the Perth Canyon (Figure 5.1; Table 5.1). Compositionally, shelf and slope sediments are a mix of skeletal material from molluscs, bryozoans and foraminifera, combined with small contributions from chemical precipitates.

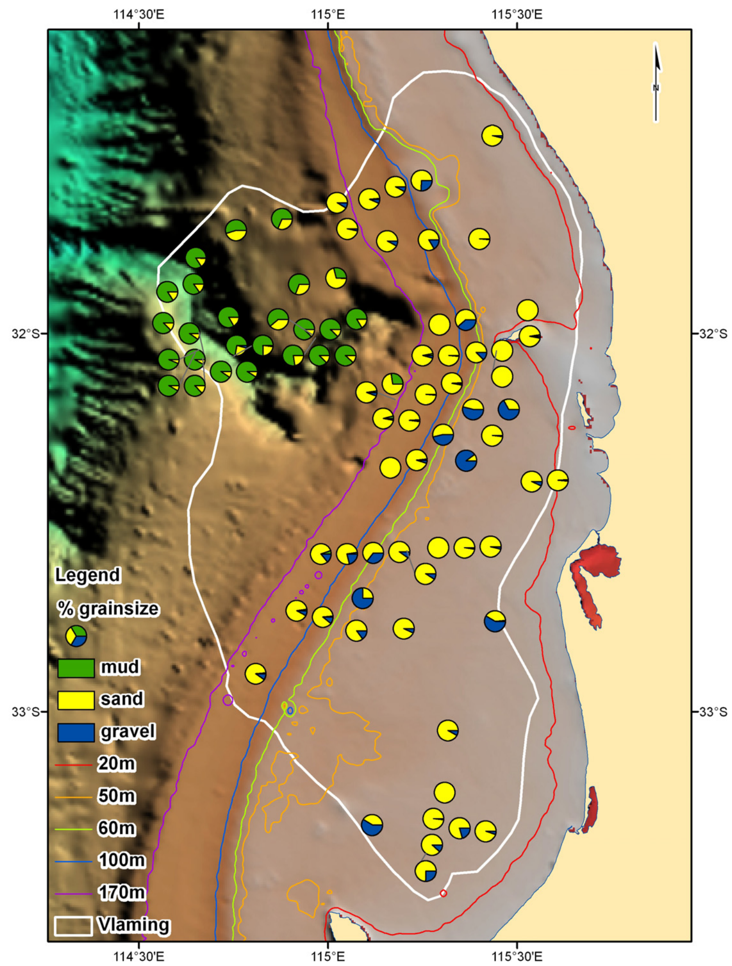


Figure 5.1: *Map of Vlaming Sub-Basin showing approximate mud, sand and gravel content of surface samples held in the marine samples database (MARS) at Geoscience Australia.*

On the Rottnest Shelf, two sediment facies are recognised, termed the Fremantle Blanket and Rottnest Blanket by Collins (1988). The Fremantle Blanket occurs in water depths of 20 to 90 m as a discontinuous cover of mostly well sorted, medium- to coarse-grained calcareous and quartzose sands, up to 0.5 m thick. The facies also has a minor fraction of very coarse sand to gravel-sized bryozoan, coral and skeletal material distributed in a belt aligned with offshore ridges near the inner shelf margin. In contrast, the limestone ridges in the nearshore and on the inner shelf are generally devoid of sediment cover, but they do have a thin (< 15 cm) algal crust.

The Rottnest Blanket extends from 90 m water depth across the outer shelf to the upper continental slope, to at least 430 m water depth. The sediment cover is 0.5 to 1 m thick and comprises fine- to medium-grained bryozoan sand that is poorly to moderately sorted, with minor amounts of other calcareous materials (i.e. foraminifera, molluscs, echinoderms). In deeper water, the deposit is silt and clay-sized and at least 0.6 m thick (Collins, 1988). The weathering of this facies, particularly glauconite impregnation of many grains, suggests that it is partly relict. This facies does support an active infauna, however, as evidenced by abundant burrow traces in water depths up to 250 m (Collins, 1988).

Table 5.1: Summary sediment data for bathymetric zones of the continental shelf for Vlaming Sub-Basin , showing average and range (in brackets) mud, sand, gravel and bulk carbonate values for samples held in the marine samples (MARS) database at Geoscience Australia (n = number of samples).

	Water depth (m)	Mud (%)	Sand (%)	Gravel (%)	n	Carbonate (%)	n
Inner shelf plain	20–50	0.2 (0–1)	83 (10–100)	17 (0–89)	27	65 (13-96)	27
Inner shelf ridges	50–60	0.4 (0–1)	39 (25–53)	60 (46–74)	2	95	1
Inner shelf reef	60–100	0.4 (0–1)	76 (61–88)	23 (11–38)	6	93 (90-95)	6
Outer shelf	100–170	1.5 (0–5)	92 (76–100)	6.5 (0–21)	14	90 (87-93)	14
Upper slope	> 170	66 (0.6–94)	33 (6–97)	1.0 (0–9)	31	81 (52-94)	30

5.2.2 Perth Canyon Sediments

The 2005 Geoscience Australia survey on RV *Southern Surveyor* provided new information on the seabed sediments of the deeper water areas of Vlaming Sub-Basin, in particular the Perth Canyon and adjacent slopes. In addition, the first ever underwater photographs of these environments were taken (Heap et al. 2008). Seabed photographs from each of the four canyons and surrounding slopes reveal a varied and abundant benthic infauna, as evidenced by fresh burrows and crawling trails, faecal pellets, live sponges and corals (Heap et al. 2008).

Within the vicinity of the Perth Canyon, mean grain size of surface sediments ranges from coarse sand on the outer shelf, to fine and very fine sand on the continental slope, and coarse silt (mud) in the Perth Canyon (Figure 5.2). Sediments in the Perth Canyon are distinctly muddier (average mud content 85%) than on the adjacent continental slope (average 64%; Figure 5.3). However, the canyon is not uniformly mud-rich, with the SW slope and canyon floor having higher mud content (86% to 94%) than the steeper NE and NW flanks (61% to 78%). Overall, the trend is toward increased mud content into deeper water. Conversely, there is a weak trend of reduced bulk carbonate content into deeper water, from >90% on the outer shelf to an average of ~78% on the lower slope of Perth Canyon (Figure 5.4).

Sediments in the area are mainly calcareous and very poorly sorted, dominated by fossil remains of planktonic and benthic foraminifera, with minor proportions of radiolarians, ostracods, pteropods and sponge spicules (Heap et al. 2008). Bulk carbonate content ranges from 52% to 92% (Figure 5.4). A distinction between the composition of sediments from upper continental slope and lower slope to canyons exists. Thus, sediments from the upper slope are dominated by benthic forams whereas deeper water deposits are mostly planktonic forams (50 – 97%). In addition, samples from the upper Perth Canyon comprise skeletal material interpreted as reworked sediment from the outer continental shelf, presumably from the Rottnest Blanket (Heap et al. 2008). This interpretation is supported by measurements of foram fragmentation in surface sediment samples which show a higher concentration of fragmented material for upper slope and upper Perth Canyon samples. Fragmentation is assumed to be a product of down-slope and down-canyon transport. Similar trends are reported for the blind canyons (Heap et al. 2008).

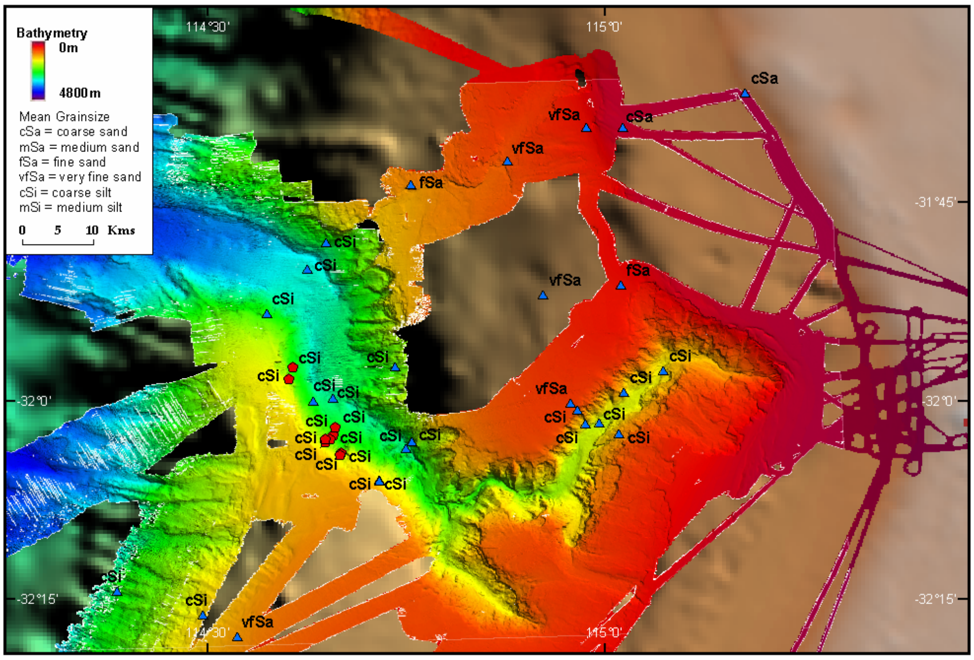


Figure 5.2: *Multibeam sonar image of the Perth Canyon showing sediment texture based on mean grain size for samples collected from the canyon and adjacent slopes (reproduced from Heap et al. 2008).*

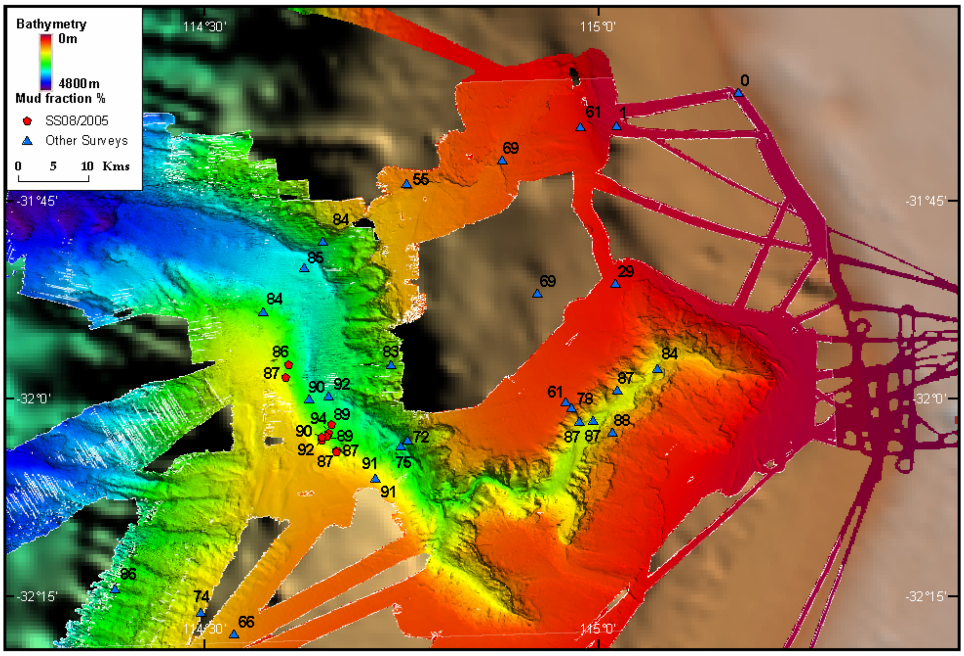


Figure 5.3: *Multibeam sonar image of the Perth Canyon showing mud content (%) for samples collected from the canyon and adjacent slopes (reproduced from Heap et al. 2008).*

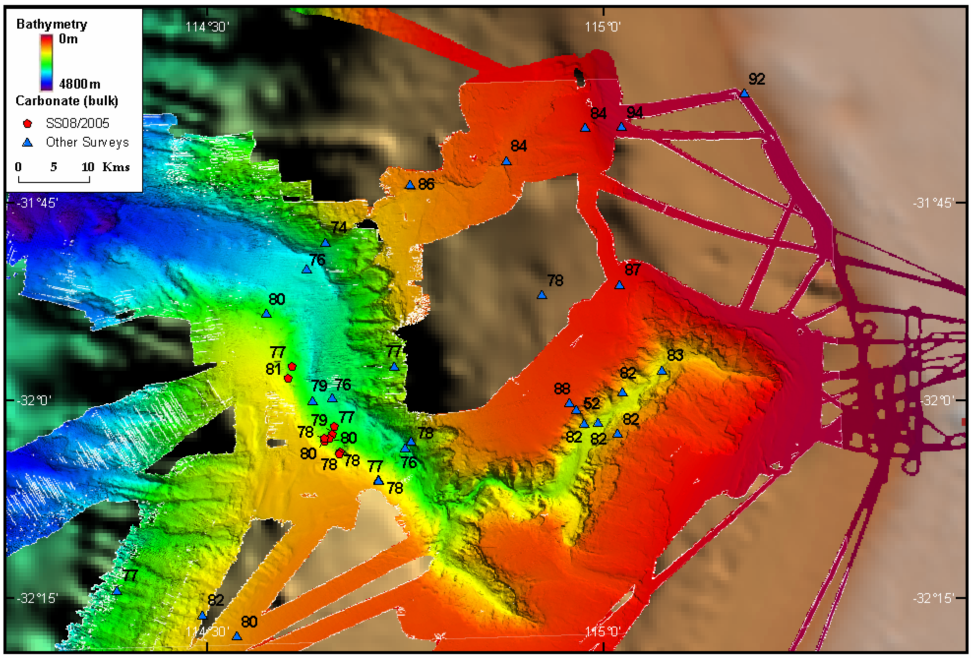


Figure 5.4: *Multibeam sonar image of the Perth Canyon showing bulk carbonate content (%) for samples collected from the canyon and adjacent slopes (reproduced from Heap et al. 2008).*

The composition of near-surface sediments that drape the walls and floor of Perth Canyon is revealed by four gravity cores collected by the RV *Southern Surveyor*. Maximum core penetration was 1.76 m into calcareous ooze, dominated by foraminifers and other nannofossils including sponge spicules (Heap et al. 2008). Three sediment facies are recognised on the basis of sedimentary structures and colour differences, from top to bottom as follows: Facies A is massive, light brown and up to 45 cm thick; Facies B is a 15 – 78 cm thick bed of laminated ooze with dark organics, burrows and interbeds, and; Facies C is massive to weakly laminated, burrowed, very light brown to white and at least 1.1 m thick. The contact between Facies A and B is graded, whereas the upper contact of Facies C is sharp, indicating a hiatal surface or weathering boundary. Further details of results on all sediment analyses are presented in the report for Geoscience Australia Survey SS08/2005 (Heap et al. 2008).

5.3 MENTELLE BASIN

Information regarding surface sediment types within the Mentelle Basin is largely restricted to the blind canyons (Busselton, Geographe and Bunbury Canyons) of the eastern depocentre and adjacent lower continental slope. A total of 16 samples exist for the canyons, two on adjacent slopes and one sample is available for the western depocentre (Figure 5.5). All samples were collected during three Geoscience Australia surveys in 2005 (SS07/2005, SS08/2005 & SS09/2005), with full details available in Heap et al. (2008).

The dominant sediment size of the eastern Mentelle Basin is coarse silt (mud) (Figure 5.6). Mud content ranges from 64% to 91%, with highest values in Busselton Canyon (Table 5.2). Most samples include a fraction of very fine sand in the range of 9% to 36%, with higher values (~20%) for samples from the floor of Geographe Canyon and the lower continental slope (Figure 5.7). From the available data, however, there is no clear pattern in sand distribution within the sampled area, as both lower slope and canyon environments yielded samples with similar range of sand content (Table 5.2). Gravel is present only as a trace in samples collected from the eastern Mentelle Basin.

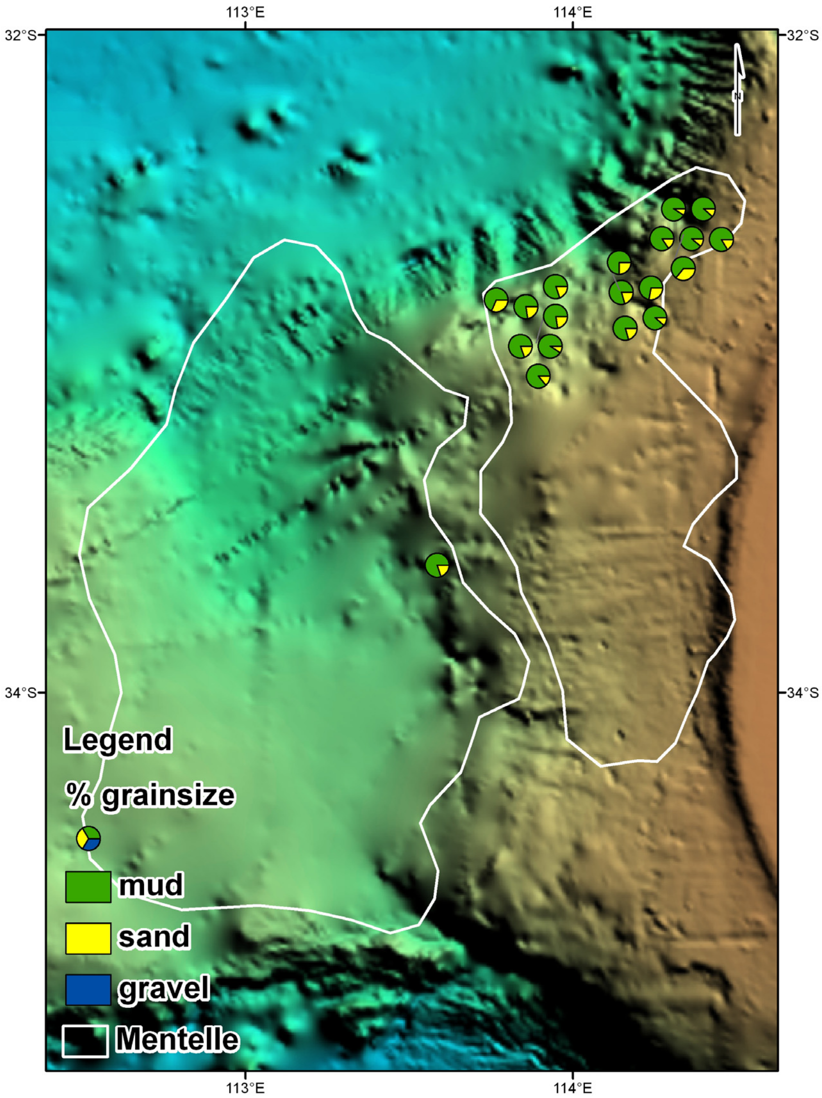


Figure 5.5: *Map of the Mentelle Basin showing approximate mud and sand content (%) of 19 surface sediment samples held in the marine samples database (MARS) at Geoscience Australia.*

Table 5.2: Summary sediment data for blind canyons and adjacent slopes in the eastern Mentelle Basin and western Mentelle Basin, showing average and range (in brackets) mud, sand, gravel and bulk carbonate values for samples held in the marine samples (MARS) database at Geoscience Australia (n = number of samples).

	Mud (%)	Sand (%)	Gravel (%)	CaCO3 (%)	n
Busselton Canyon	83 (64– 90)	17 (9–36)	0.03 (0-0.2)	80 (70–88)	5
Geographe Canyon	79 (72–89)	21 (11–28)	0.2 (0-0.7)	82 (80–83)	4
Bunbury Canyon	80 (68 – 91)	20 (9–32)	0.07 (0-0.3)	82 (80–84)	7
Lower slope	81 (79–83)	18 (16–20)	0.05 (0-0.1)	84.5 (84–85)	2
Western Mentelle	80	20	0	78	1

The composition of Mentelle Basin surface sediments is dominantly carbonate, with all samples having bulk carbonate content greater than 70% (Figure 5.8). The non-carbonate fraction of all samples comprises a mixture of siliceous sediment and unidentifiable fragments (Heap et al. 2008). Again, spatial patterns in the distribution of carbonate are poorly developed, with no consistent trends associated with depositional environment or water depth.

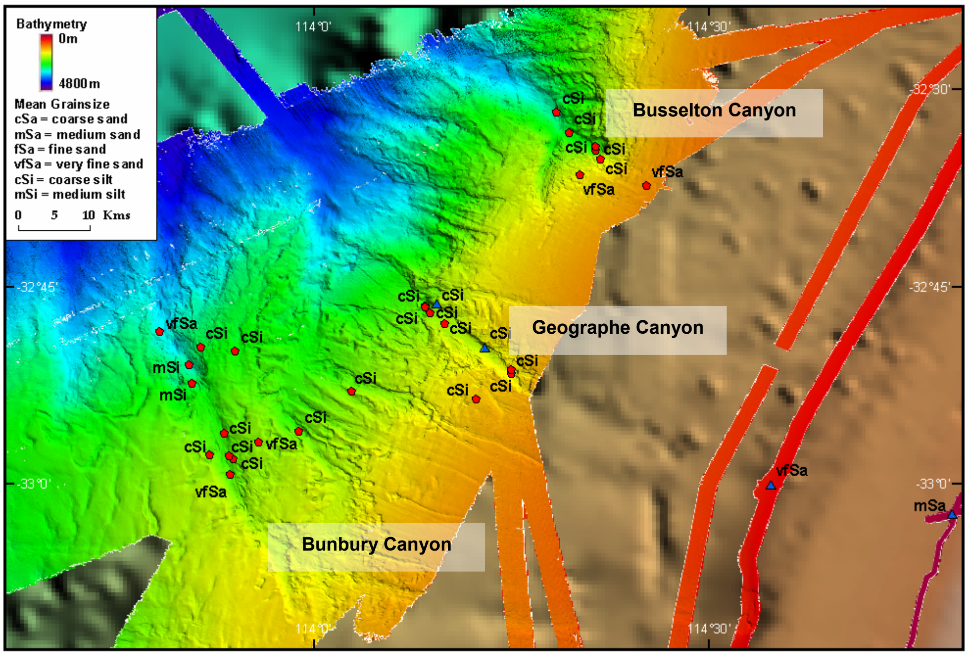


Figure 5.6: *Multibeam sonar image of northern area of the eastern Mentelle Basin showing sediment texture based on mean grain size for samples collected from the blind canyons and adjacent slopes (reproduced from Heap et al. 2008).*

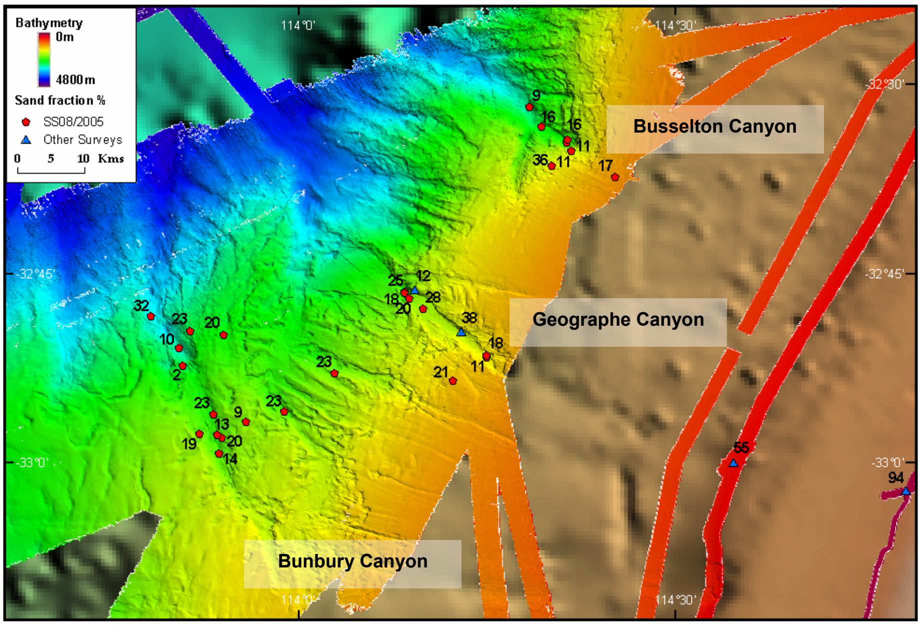


Figure 5.7: *Multibeam sonar image of northern area of the eastern Mentelle Basin showing sand content (%) for samples collected from the blind canyons and adjacent slopes (reproduced from Heap et al. 2008).*

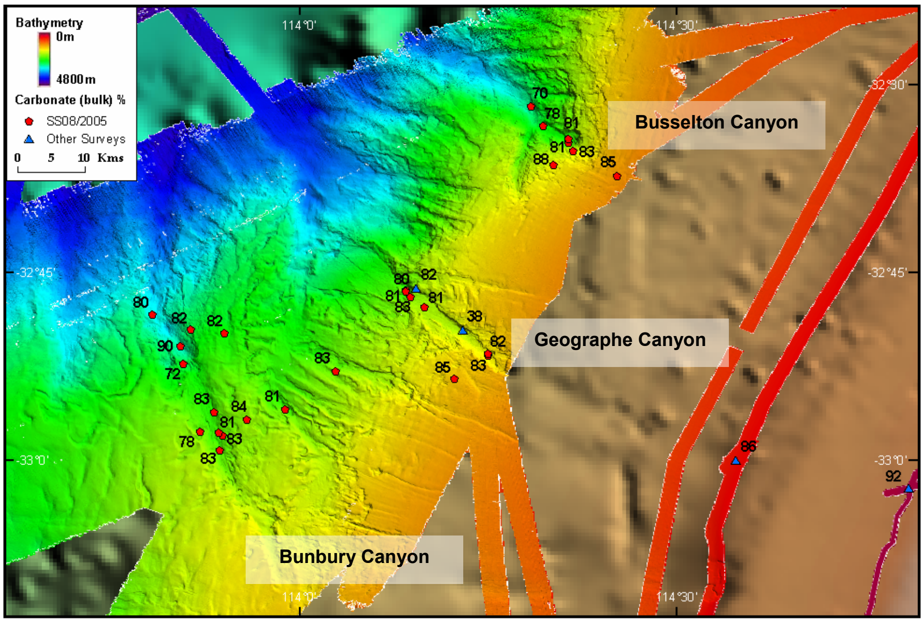


Figure 5.8: *Multibeam sonar image of northern area of the eastern Mentelle Basin showing bulk carbonate content (%) for surface sediment samples collected from the blind canyons and adjacent slopes (reproduced from Heap et al. 2008).*

Short cores were also collected from Busselton Canyon and Bunbury Canyon to document the near-bed sediment facies (Heap et al. 2008). Three cores were recovered from Busselton Canyon to a maximum depth of 4 m and two cores from Bunbury Canyon to a maximum of 2.95 m. In all cases, sediments are fossil-rich calcareous ooze comprising three facies that are similar to those described from the Perth Canyon. However, at some of these sites Facies A and B in the succession are repeated through the sediment record and each facies tends to be thicker (i.e. Facies A & B up to 1 m, Facies C up to 2.9 m; Heap et al. 2008). Additional information on the physical properties of these cores and those from Perth Canyon, including wet bulk density, magnetic susceptibility and fractional porosity are reported in Heap et al. (2008). These descriptors generally support the sediment facies divisions noted here, with the exception of bulk density which appears to have been distorted by sediment compaction during the coring process.

5.4 SUMMARY

Within the Vlaming Sub-Basin, clear bathymetric trends in sediment type exist from the inner shelf to the lower continental slope. Textural differences are best developed across the shelf, as shown by the differences between the sediment facies of the Fremantle Blanket and Rottnest Blanket. From the outer shelf and onto the continental slope, sediment variability is more subtle, involving a trend toward increased mud content with depth. The character of sediments in the Perth Canyon differs slightly from that of the adjacent continental slope, with the former having higher mud content and a trend of increased mud content down-canyon. Overall, these textural patterns are interpreted as evidence for preferential transport and deposition of fines from the outer shelf and upper continental slope along the Perth Canyon and toward the deep ocean.

Spatial variations in the composition of sediment across the Vlaming Sub-Basin area are also attributed to reworking from the outer shelf to slope, particularly during storms. The limestone ridges of the outer Rottnest Shelf are a key area of localised sediment production, due to the abundance of bryozoans, sponges and large foraminifera growing on the ridges. Proximity of the ridge complex to the shelf break allows for downslope transport of fine sand and silt sized fragments of bryozoans and foraminifera, plus sponge spicules, onto the upper continental slope. With increased distance down-slope, sediment is sorted further into the mud-rich facies that characterises the Perth Canyon and adjacent slopes of the Vlaming Sub-Basin.

In the deeper waters of the Mentelle Basin, surface sediments are more uniform in texture across the lower continental slope and within the blind canyons. Silt is the dominant grain size, forming a slightly sandy, carbonate-rich mud. The lack of a clear difference between slope and canyon sediments indicates that deposits in these areas essentially derive from the same planktonic and benthic biological sources. Similarly, there is no strong sedimentary evidence for reworking within canyons, as would be shown by consistent down-canyon textural trends such as observed in the Perth Canyon. This interpretation is supported by results from shallow cores. In particular, the preservation of well defined facies, facies contacts and fine-scale sedimentary structures, such as laminae, are good indicators of near-surface stability at the local (sub-metre) scale. Burrowing by infauna appears to be the only evidence for sediment disturbance at this scale. Beyond the canyons, our understanding of sediments in the remainder of the Mentelle Basin remains poor.

6. Physical Oceanography

6.1 INTRODUCTION AND DATA SOURCES

South-western Australia which includes the Vlaming Sub-Basin and Mentelle basins is dominated by the influence of the Leeuwin Current System: the Leeuwin Current, Leeuwin Undercurrent and the Capes Current, a wind-driven shelf current system (Ridgeway and Condie, 2004; Pattiaratchi, 2006; Woo and Pattiaratchi, 2008). The region has been subjected a number of recent studies based on field measurements and numerical modelling. These include: Gersbach et al. (1999); Feng et al. (2003); Ridgway and Condie (2004); Pattiaratchi (2006); Rennie et al. (2007); Woo and Pattiaratchi (2008). Tidal measurements are limited to coastal stations at Fremantle, Bunbury, Busselton and long-term wave measurements are available off Rottnest Island and Cape Naturaliste. Information for this review of the physical oceanography of the Vlaming Sub-Basin and Mentelle Basins has been drawn from key journal references, the CSIRO Atlas of Regional Seas (CARS) and the National Marine Bioregionalisation of Australia GIS (Department of Environment and Heritage, 2005).

6.2 CLIMATIC DESCRIPTION

The following sub-sections present both the annual mean and monthly means representative of seasonal values for sea surface temperature (SST) and seafloor temperature and sea surface and seafloor salinity. Primary productivity (PP) in surface waters and the mixed layer depth (MLD) are also presented. The information is a subset of the National Marine Bioregionalisation GIS, which was drawn from the CARS data base.

6.2.1 Temperature

On a global scale ocean temperature varies with latitude and largely reflects the balance of the intensity of solar radiation incident on the surface of the oceans and the heat loss from the ocean surface. The ocean temperature influences the range of species present in a region. It also influences oceanic circulation through its effect on density and pressure gradients. Localised spatial and temporal variation in oceanic temperature often indicates the incursion of ocean currents from outside the region and the mixing of different water masses.

The SST over the Vlaming Sub-Basin is dominated by the influence of the Leeuwin Current which advects warm tropical water through the basin. The temperatures vary between 22°C at the northern end of the sub-basin to 20°C at the southern end (Figure 6.1). Over the Mentelle basin, the eastern section is influenced by warmer Leeuwin Current whilst the western end is influenced by the cooler waters of the southern Ocean. The season cycle of the SST over the region are due to a combination of solar heating and changes in the currents: in January, SST across the region is almost uniform with temperature of 20°C, with slightly colder water present on the continental shelf due to the Capes current, a wind driven cold-water current (Figure 6.2). In April, the warmer water advected into the region by the Leeuwin current is evident (Figure 6.3) whilst in July the warmer Leeuwin current can be identified clearly as the shelf and offshore waters being cooler (Figure 6.4). In October, there is cooling of the waters due to the decrease in the strength of the Leeuwin Current (Figure 6.5). The annual mean seafloor temperature varies by up to 20°C – on the continental shelf the influence of the Leeuwin Current results in higher temperature whilst at around 1000 m in the sub-basin the temperature is 5°C and decreases to 3°C at bottom depths of 2000 m (Figure 6.6).

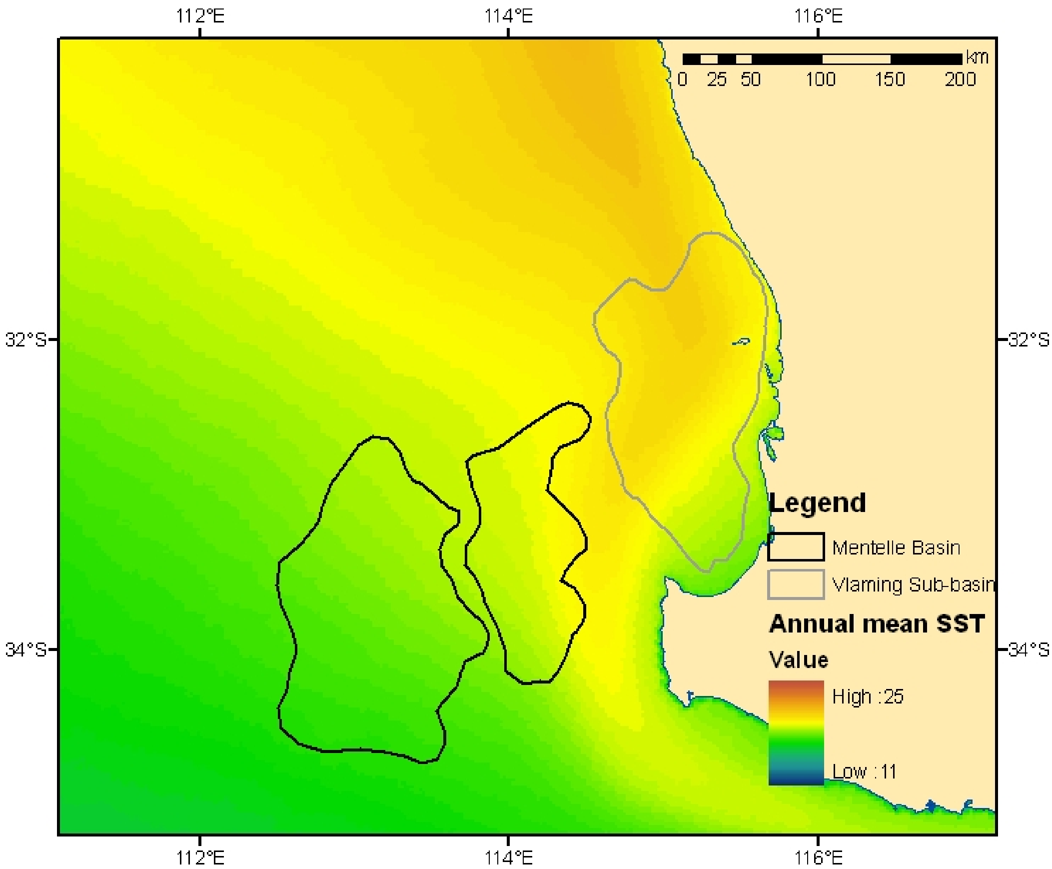


***Figure 6.1**: Annual mean SST over the Vlaming Sub-Basin and Mentelle Basin obtained from the National Marine Bioregionalisation GIS (Department of Environment and Heritage, 2005).*

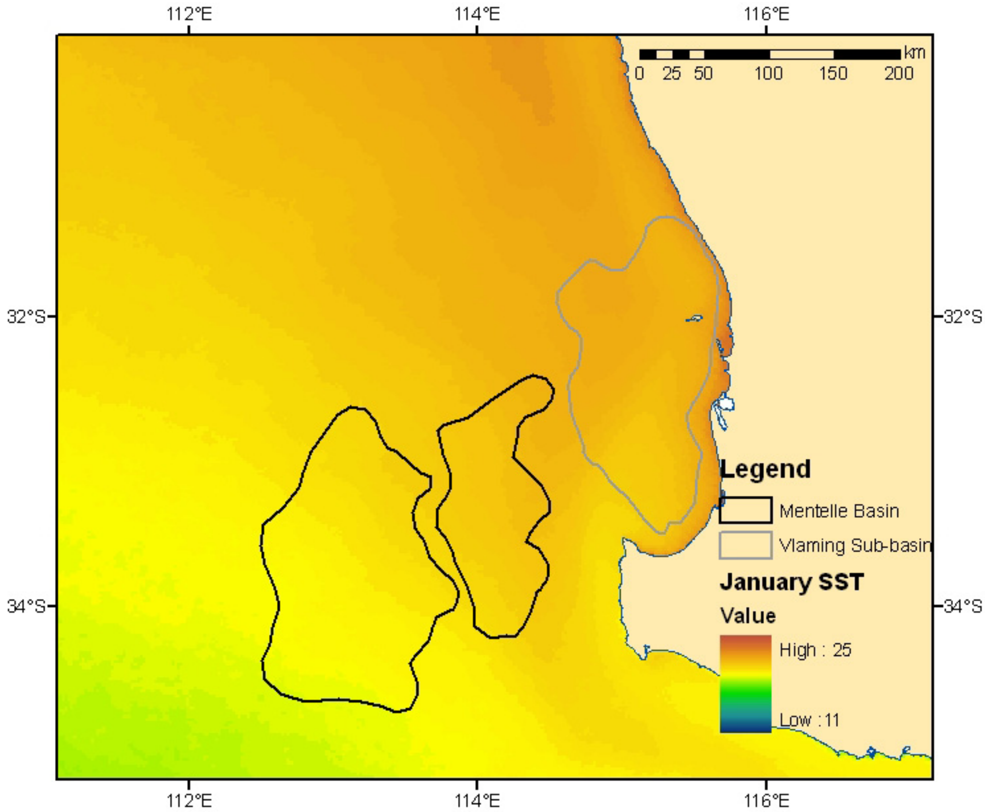


Figure 6.2: *Mean January SST over the Vlaming Sub-Basin and Mentelle Basinobtained from the National Marine Bioregionalisation GIS (Department of Environment and Heritage, 2005).*

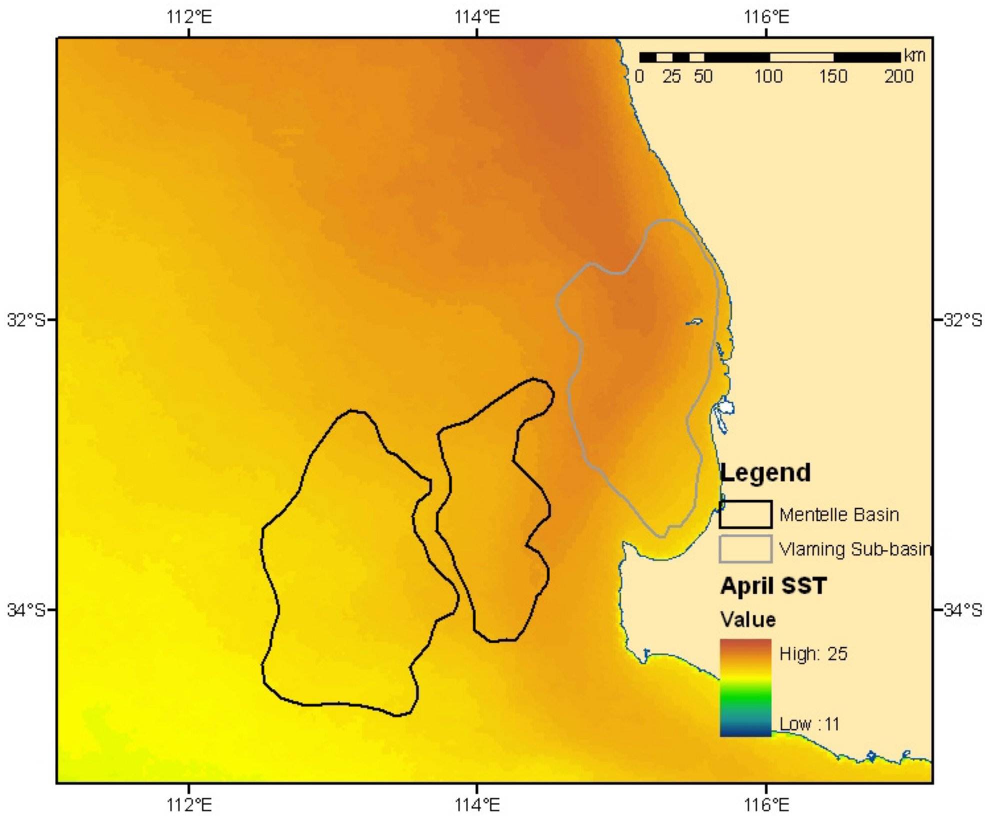


Figure 6.3: *Mean April SST over the Vlaming Sub-Basin and Mentelle Basinobtained from the National Marine Bioregionalisation GIS (Department of Environment and Heritage, 2005).*

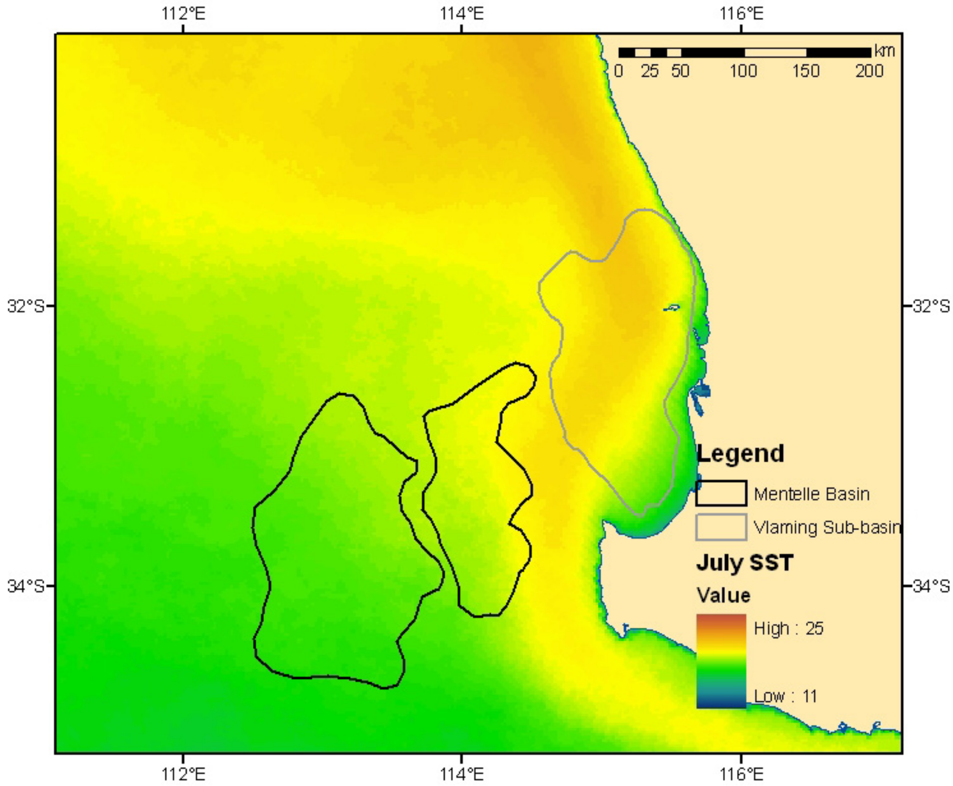


Figure 6.4*: Mean July SST over the Vlaming Sub-Basin and Mentelle Basinobtained from the National Marine Bioregionalisation GIS (Department of Environment and Heritage, 2005).*

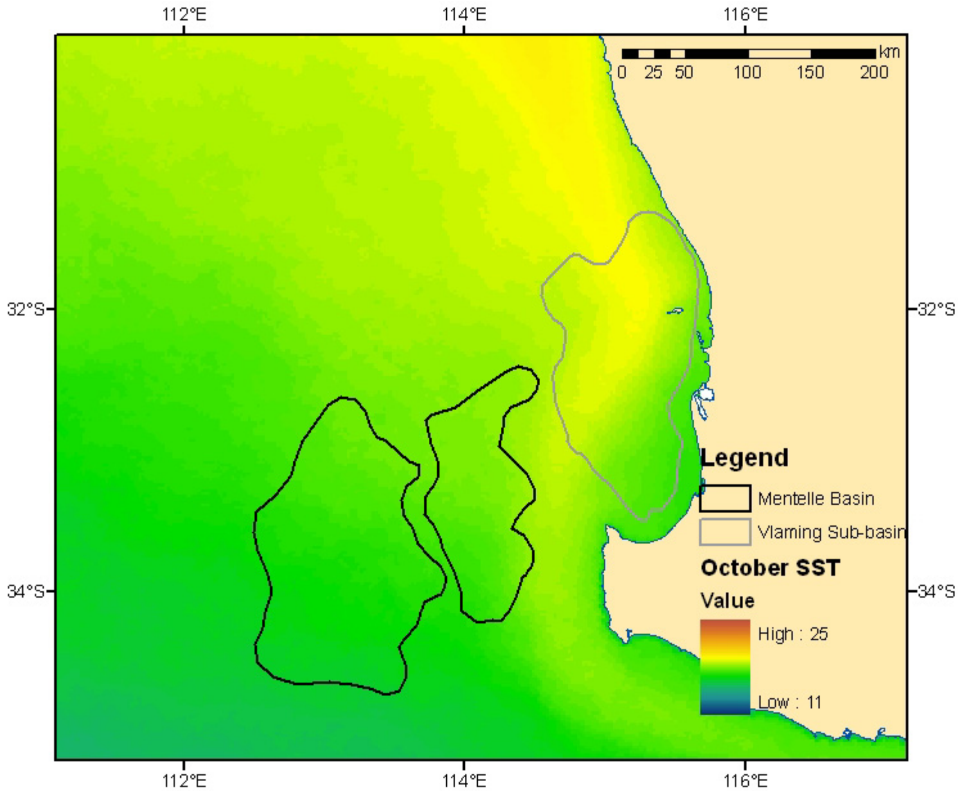


Figure 6.5*: Mean October SST over the Vlaming Sub-Basin and Mentelle Basin obtained from the National Marine Bioregionalisation GIS (Department of Environment and Heritage, 2005).*

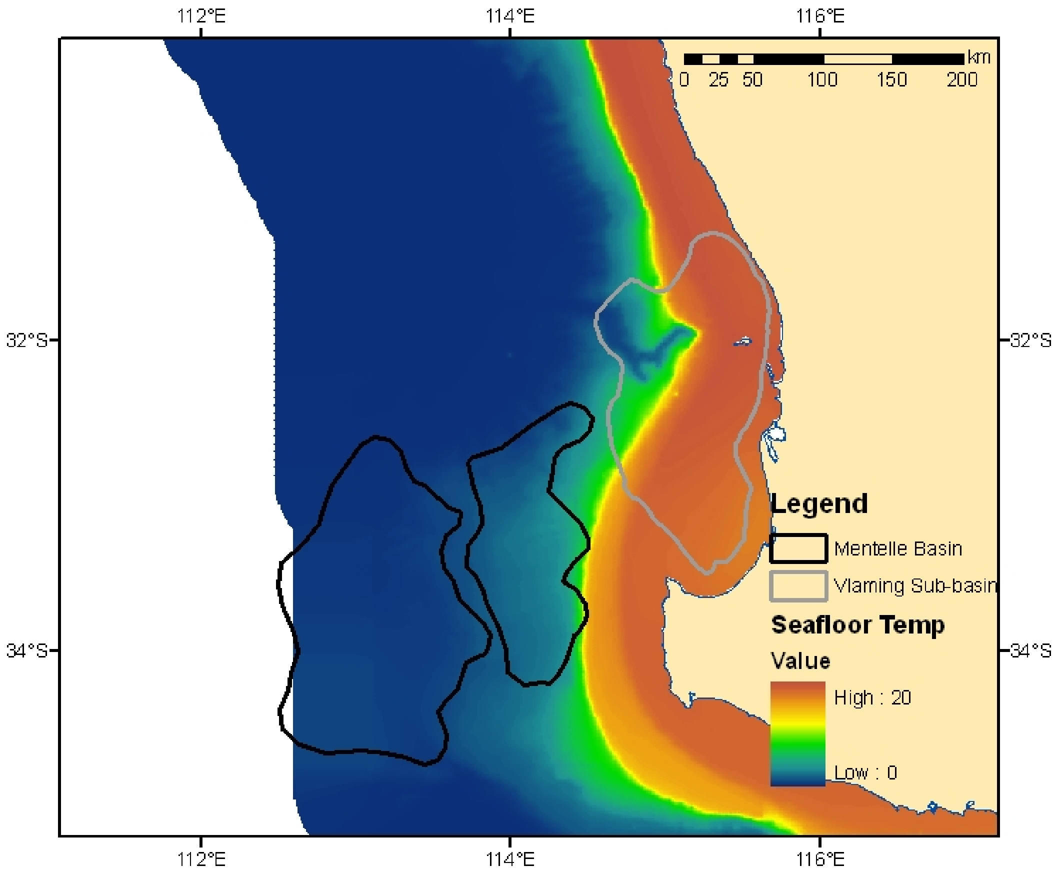


Figure 6.6*: Annual mean seafloor temperature over the Vlaming Sub-Basin and Mentelle Basin obtained from the National Marine Bioregionalisation GIS (Department of Environment and Heritage, 2005).*

6.2.2 Salinity

On a global scale ocean-surface salinity largely reflects the balance between evaporation and precipitation. The ocean salinity influences circulation through its effect on density and pressure gradients. Together salinity and temperature determine density and distinguish water masses.

Localised spatial and temporal variation in salinity often indicates the incursion of ocean currents from outside the region and the mixing of different water masses.

The annual mean surface salinity (Figure 6.7) in the region ranges between 34 and 36 (note that under international convention salinity does not has units but the unit quoted here are equivalent to ppt) due to the presence of two major water masses in the region. The lower salinity water in the northern section and extending onto the Vlaming subregion (Figure 6.7) is due the Leeuwin Current which transports warmer lower salinity of tropical origin southwards (section 3.2). The higher salinity water present over the Mentelle sub region (Figure 6.7) and extending westward is the southern Indian central water (SICW) is the main surface water mass in the southern Indian ocean with the higher salinity being derived from higher evaporation in the sub-tropical regions. The annual mean seafloor salinity has a similar range to that of the surface: 34 to 36 (Figure 6.7). Higher salinity water is present in the waters < 300 m and is due to the influence of the SICW which is advected onto the Leeuwin Current in this region. The salinity changes at along different water depths reflect the different water masses present (Table 6.1) in the region (Woo and Pattiaratchi, 2008). These water masses were observed in the vertical distribution of salinity and dissolved oxygen as interleaving layers of salinity and dissolved oxygen. In terms of increasing depth these water masses were (Table 6.1):

(i) lower salinity tropical surface water (TSW)
(ii) higher salinity south Indian central water (SICW)
(iii) higher oxygen subantarctic mode water (SAMW)
(iv) lower salinity Antarctic intermediate water (AAIW)

Table 6.1: Characteristics of the water masses found along the 1000-m isobath along the West Australian coastline.

Water mass	Temperature range	Salinity range	Dissolved oxygen range
Tropical surface water (TSW)	22–24.5 ^{0}C	34.7–35.1	200–220 μM/L
South Indian central water (SICW)	12–22 ^{0}C	35.1–35.9	220–245 μM/L
Subantarctic mode water (SAMW)	8.5–12 ^{0}C	34.6–35.1	245–255 μM/L
Antarctic intermediate water (AAIW)	4.5–8.5 ^{0}C	34.4–34.6	115–245 μM/L

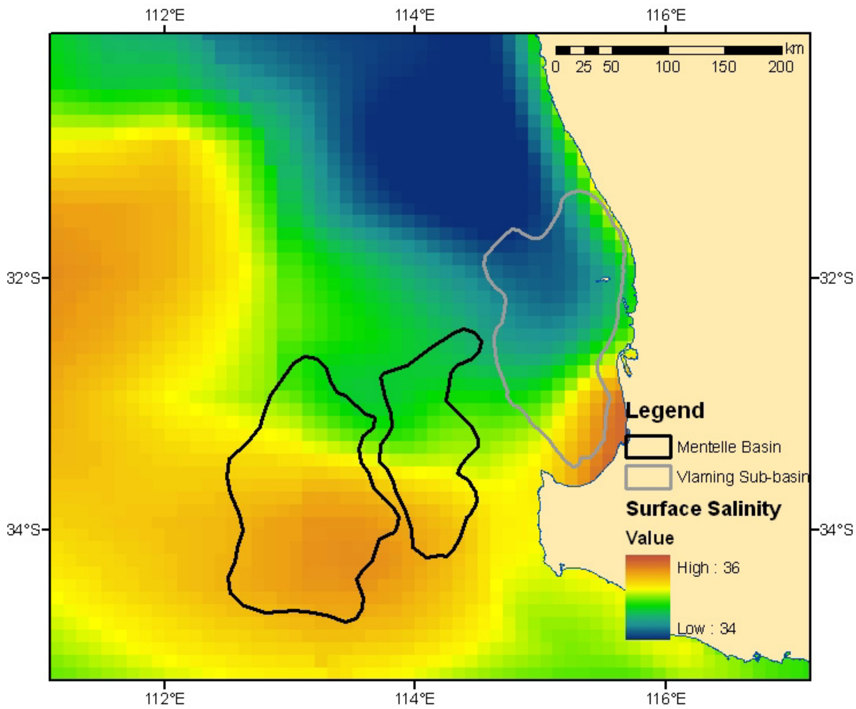


Figure 6.7*: Annual mean surface salinity over the Vlaming Sub-Basin and Mentelle Basin obtained from the National Marine Bioregionalisation GIS (Department of Environment and Heritage, 2005).*

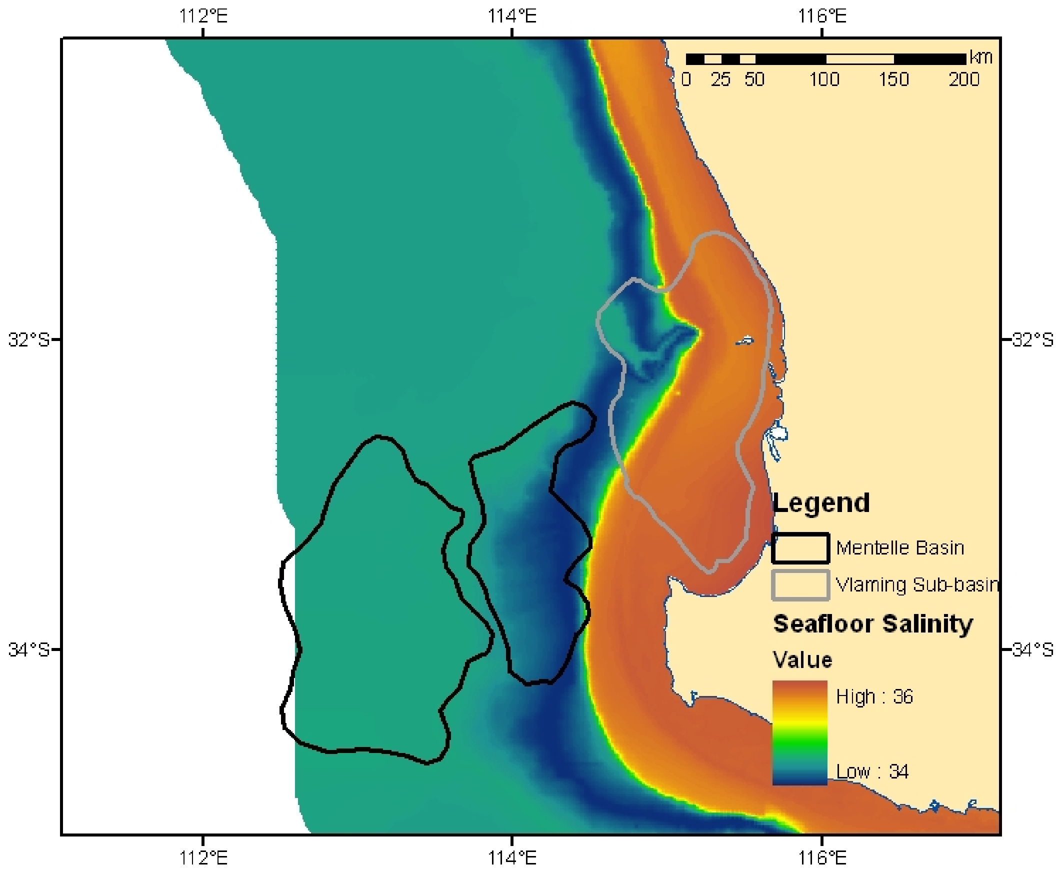


Figure 6.8*: Annual mean seafloor salinity over the Vlaming Sub-Basin and Mentelle Basin obtained from the National Marine Bioregionalisation GIS (Department of Environment and Heritage, 2005).*

6.2.3 Primary Productivity

The amount of carbon fixed by marine organisms (plants and algae) through photosynthesis is defined as primary production. Here, the organisms, using sunlight and nutrients convert carbon dioxide into carbon. Primary productivity in the ocean is defined as the amount of carbon, per unit time and unit area. In general, regions along the eastern sections of ocean basins are highly productive ecosystems, supporting high primary productivity and large pelagic finfish stocks. This is due to the earth's rotation (the 'Coriolis' force) and shore-parallel equatorward winds upwelling cold, nutrient-rich water. Here, surface waters in the weak currents are deflected offshore and replaced by the upwelling of cold, nutrient-rich water from depth. Fluxes of "new" nitrogen (as nitrate) into the euphotic zone stimulate high primary production rates (Barber and Smith 1981; Mann and Lazier 1996). The proliferation of large (> 5-µm diameter) phytoplankton species helps develop a herbivorous food web (Cushing 1989;

Legendre and Rassoulzadegan 1995), with a short trophic pathway causing the large finfish stocks common to eastern boundary currents.

Off the south-west Australian coast, however, although the prevailing wind regime is similar to other eastern ocean margins, the waters have little nutrients and low primary production (oligotrophic) due to the influence of the Leeuwin Current which is low in nutrients. However, under certain conditions, for example, under higher winds during the summer and/or interaction between surface and subsurface currents and topographic features (submarine canyons), regions of higher productivity are present along the coast. Of the four such regions identified in Western Australia (south of Shark Bay), three of these regions: Perth Canyon; Cape Mentelle upwelling regions, and the Leeuwin Current eddy fields influence the Vlaming and Mentelle sub regions (see section 6.7).

The study region is characterised by low nutrients and thus is a region of low primary productivity. This is reflected in the annual mean primary production (Figure 6.9) which indicates higher values in the shallow coastal regions decreasing offshore. The satellite derived primary productivity limited to an assessment of near-surface values only. In the study region, deep chlorophyll maximum (DCM) is generally present at the base of the euphotic zone, close to the nutricline and represents a significant proportion of the depth integrated productivity (Hansen et al., 2005). Thus satellite derived primary productivity represent surface values as the sensors do not penetrate to the base of the euphotic zone.

The annual mean primary productivity is relatively uniform in the offshore regions with rates generally < 200 mg C m^{-2} d^{-1} (Figure 6.9). Slightly elevated values are found on the continental shelf. Although high values are present in the shallow coastal waters, they are most likely to be contaminated by the effects of the seabed.

High values of primary production rates (945 mg C m^{-2} d^{-1} were measured during the summer off Cape Mentelle upwelling region whilst the maximum winter production rates were 400 mg C m^{-2} d^{-1} (Hanson et al., 2005). This reduction in productivity in winter is due to a combination of nutrient availability and the light climate. During the winter, the stronger Leeuwin Current flow lead to increased nutrient levels associated with entrainment of seasonally nutrient-enriched shelf waters. In contrast, lower surface irradiance and increased light attenuation result in lower primary productivity during the winter months. In the Perth canyon the primary production averaged 545 mg C $m^{–2}$ $d^{–1}$, ranging from 360 mg C $m^{–2}$ $d^{–1}$ in offshore waters to 760 mg C $m^{–2}$ $d^{–1}$ along the 1000 m contour of the canyon (Rennie et al., 2008).

There is considerable seasonal variation in primary productivity. In the shelf and slope waters influenced by the Leeuwin Current (Vlaming sub region) higher values of primary production occur during winter although the region between Capes Naturaliste and Leeuwin has high values from January to July (Figures. 6.10 and 6.11). In contrast, the higher values of productivity in the Mentelle region has a maximum in spring coinciding with the influence of the subtropical front (Figures. 6.12 and 6.13).

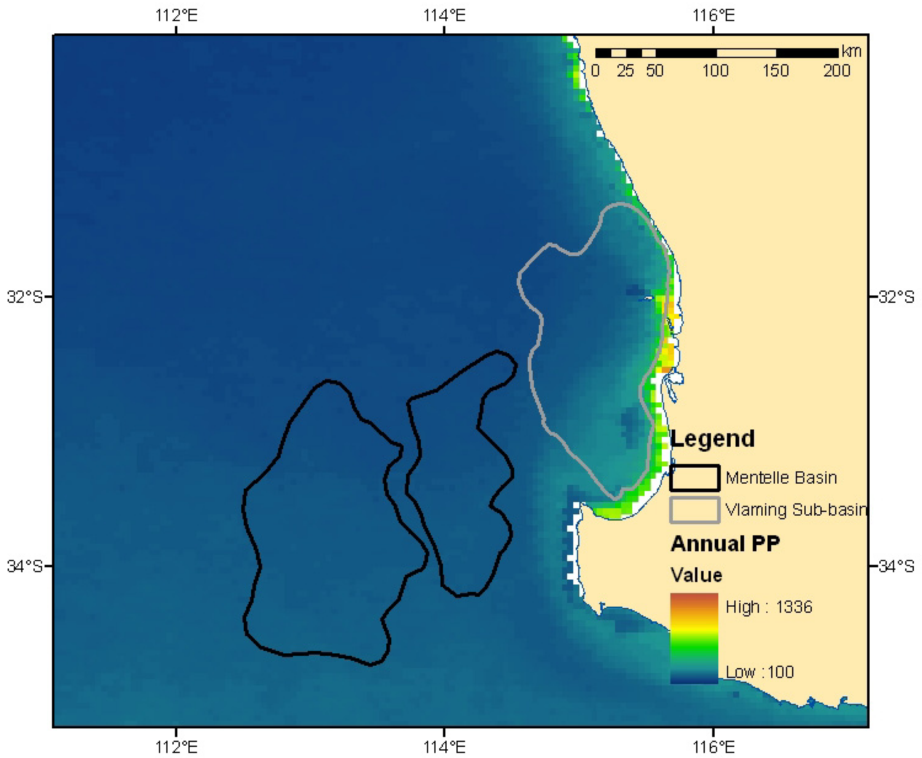


Figure 6.9: *Annual mean primary productivity (PP) over the Vlaming Sub-Basin and Mentelle Basin obtained from the National Marine Bioregionalisation GIS (Department of Environment and Heritage, 2005).*

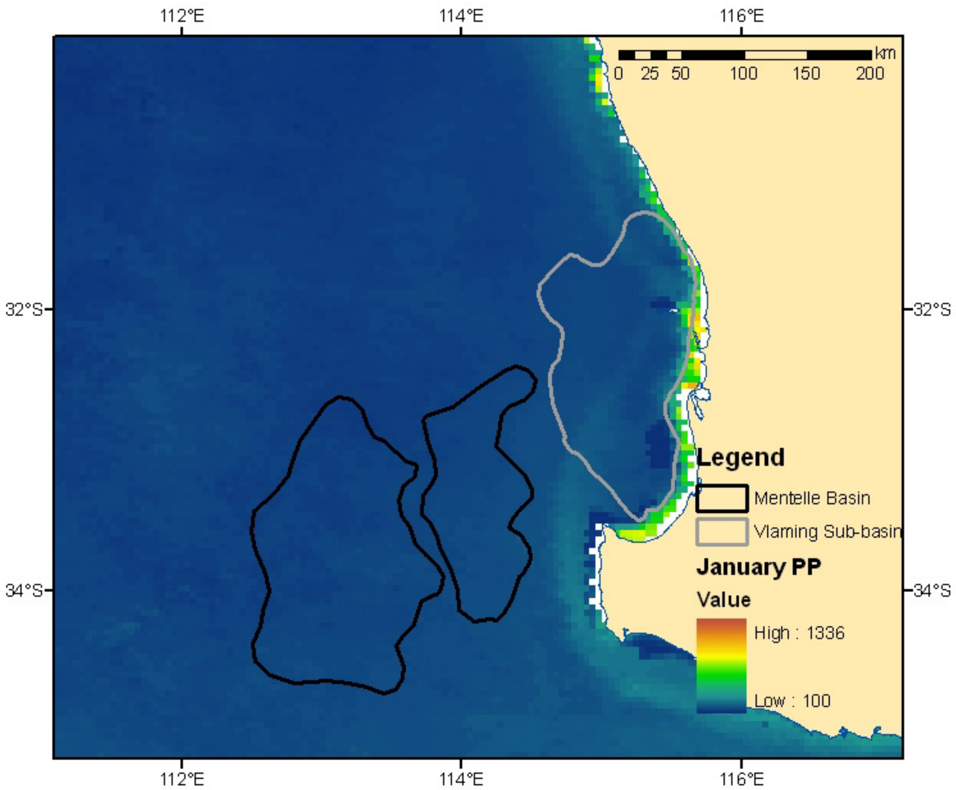


Figure 6.10: *Mean January primary productivity (PP) over the Vlaming Sub-Basin and Mentelle Basin obtained from the National Marine Bioregionalisation GIS (Department of Environment and Heritage, 2005).*

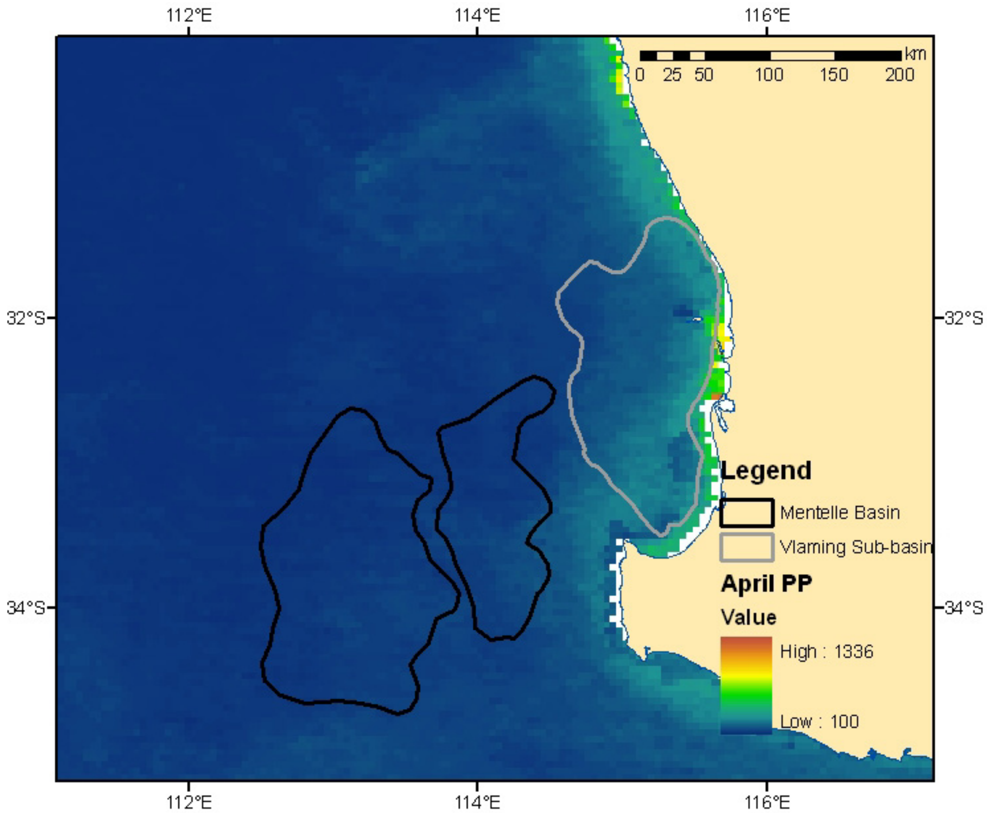


Figure 6.11: *Mean April primary productivity (PP) over the Vlaming Sub-Basin and Mentelle Basin obtained from the National Marine Bioregionalisation GIS (Department of Environment and Heritage, 2005).*

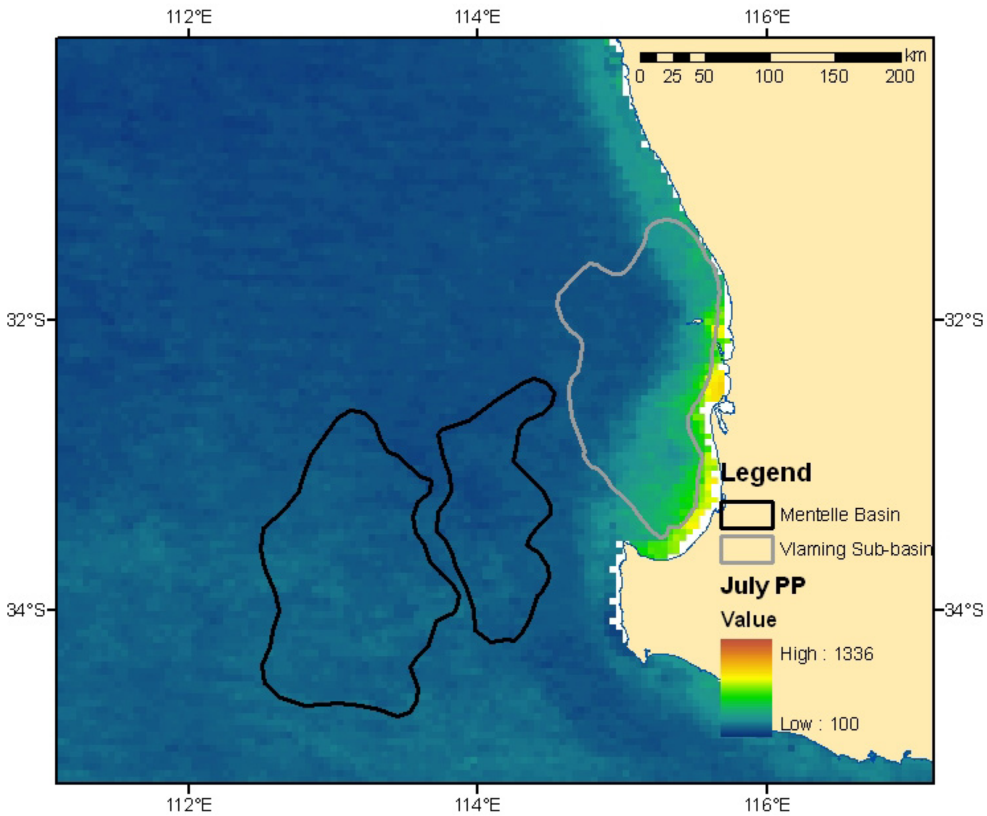


Figure 6.12: *Mean July primary productivity (PP) over the Vlaming Sub-Basin and Mentelle Basin obtained from the National Marine Bioregionalisation GIS (Department of Environment and Heritage, 2005).*

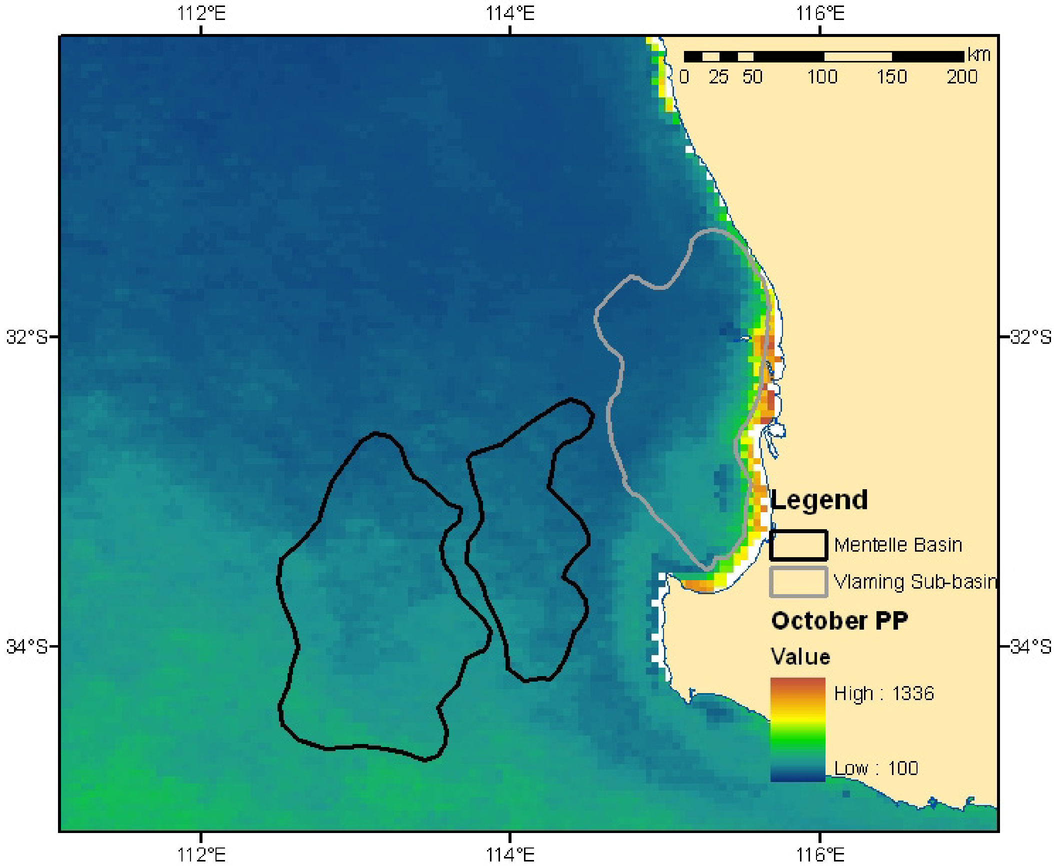


***Figure 6.13**: Mean October primary productivity (PP) over the Vlaming Sub-Basin and Mentelle Basin obtained from the National Marine Bioregionalisation GIS (Department of Environment and Heritage, 2005).*

6.2.4 Mixed Layer Depth

Wind-driven surface currents are restricted mostly to the ocean's uppermost 100 m layer termed the 'mixed layer'. It has constant salinity, temperature and density and represents the thickness of the water column that is regularly mixed and therefore exposed to the atmosphere. The pycnocline acts as a porous boundary that allows some kinetic energy to penetrate into deep water. The strongest currents generally occur in the ocean's surface layer although some surface currents such as the Leeuwin Current (discussed later) can be relatively strong to depths of several hundred meters. Mixed layer depth is highly variable, continually responding to variations in the wind, precipitation, and heating or cooling. If the mixed layer extends much deeper than the photic zone (ca. 100 m) this can limit primary productivity. The annual mean mixed layer depth over the Vlaming Sub-Basin and Mentelle Basin is ca. 50 m, which is well inside the photic zone (Figure 6.14). However, due to the high water clarity in the region the photic zone in the region, the photic zone can extend much greater than the mixed layer depth – a sub-surface chlorophyll maximum at depths between 80 and 140 m is a major feature of the study region (Hanson et al., 2005).

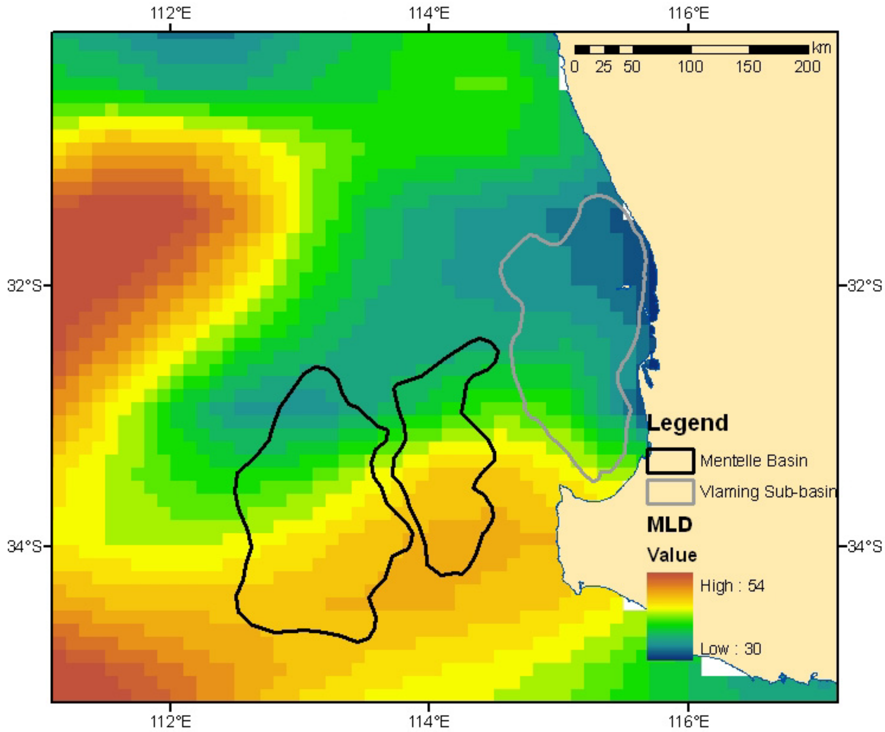


Figure 6.14*: Annual mean mixed layer depth (MLD) over the Vlaming Sub-Basin and Mentelle Basin obtained from the National Marine Bioregionalisation GIS (Department of Environment and Heritage, 2005).*

6.3 OCEANIC CIRCULATION

6.3.1 Overview

Along the south-western Australian continental shelf margin, which encompasses Vlaming Sub-Basin and Mentelle basin, there are three major current systems, collectively defined here as the Leeuwin current system (Figures. 6.15 and 6.16):

(1) Leeuwin current (LC)—a poleward surface current located along the shelf break
(2) Leeuwin undercurrent (LU)—an equatorward subsurface undercurrent on the continental slope
(3) Capes current—wind-driven equatorward surface current on the continental shelf (usually in depths < 50 m) mainly present in the summer under strong southerly wind stress

The Leeuwin current (LC) is an anomalous eastern boundary current, which carries warm, fresh tropical waters poleward along the continental shelf break. The Leeuwin undercurrent (LU) flows northward beneath the LC at depths of 200–400 m, oxygen-rich, nutrient-depleted, higher salinity (> 35.8) water at a rate of 0.32–0.40 ms^{-1} northward. The Capes current is a cooler wind driven current flowing northwards along the continental shelf off south-western Australia during the summer months in depths < 50 m.

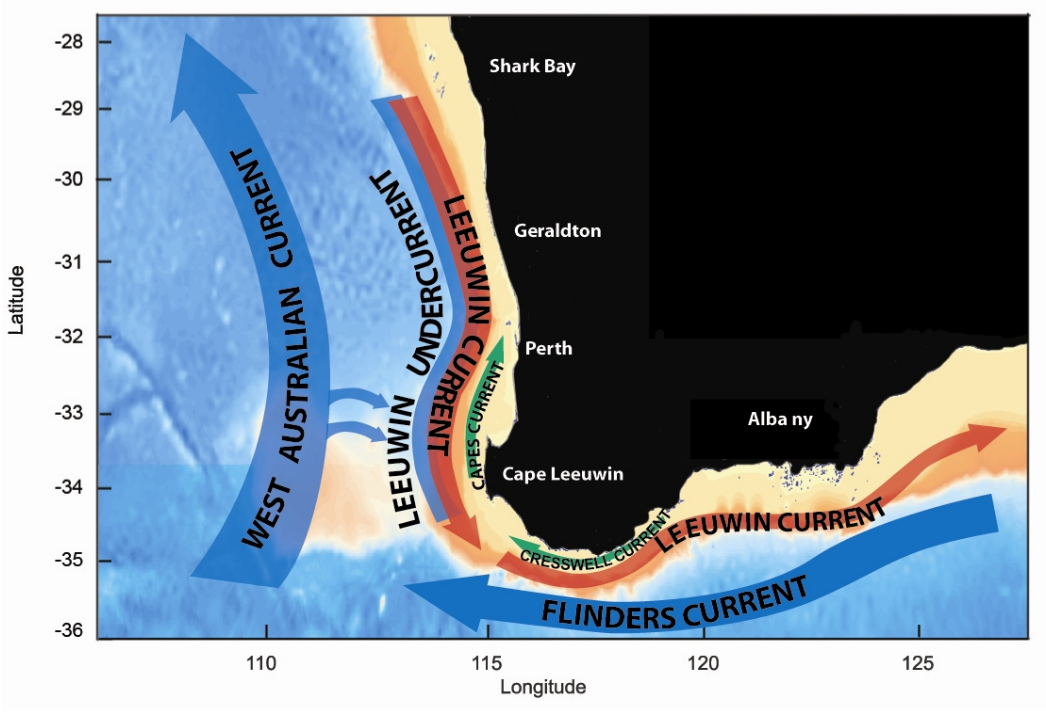


***Figure 6.15**: Schematic of the major surface and sub-surface current systems along the south-west region of Western Australia.*

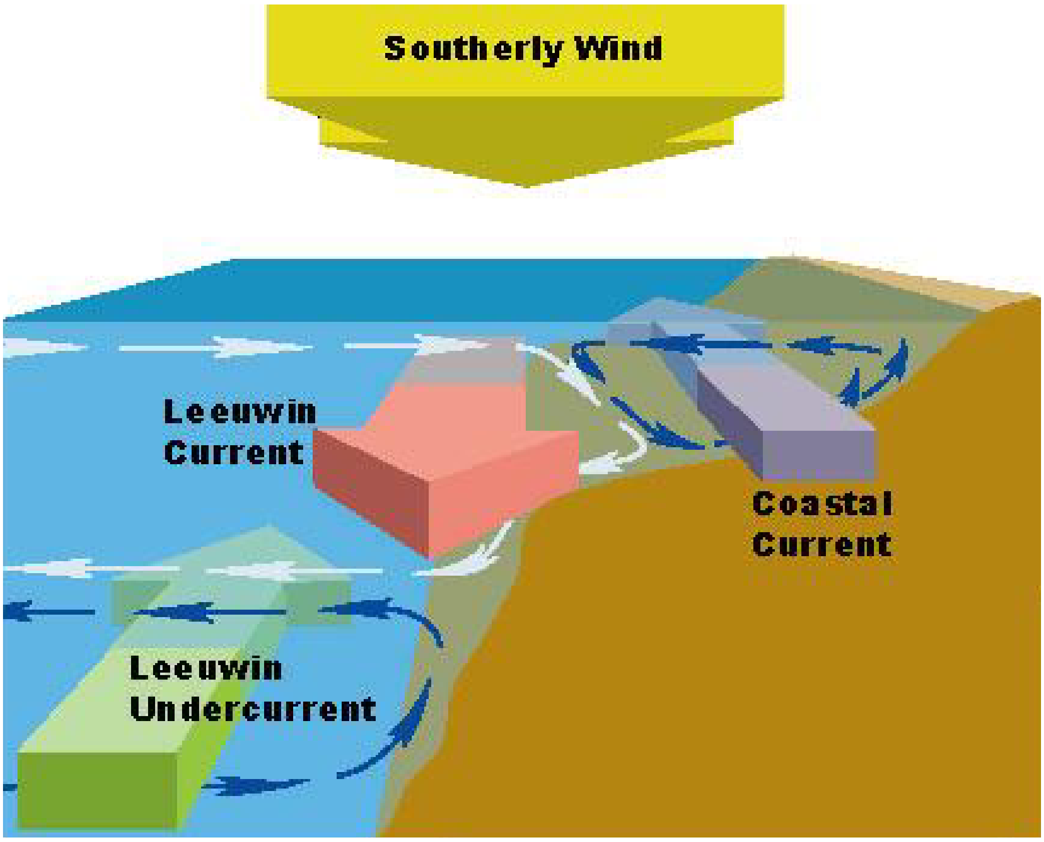


Figure 6.16: *Schematic diagram illustrating the general flow patterns at the continental margin of south-western Australia (Woo and Pattiaratchi, 2008).*

6.3.2 The Leeuwin Current

The major oceanic scale forcing along the west Australian coast is due to the Leeuwin Current (LC), a poleward eastern boundary current. The LC is a shallow (< 300 m) narrow band (< 100 km wide) of relatively warm, lower salinity water of tropical origin that flows southward, mainly above the continental slope from Exmouth to Cape Leeuwin (Church et al., 1989; Smith et al., 1991; Ridgway & Condie, 2004). The maximum flow of the current is located at the 200m isobath. At Cape Leeuwin it pivots eastward, spreads onto the continental shelf and flows towards the Great Australian Bight (Figure 6.15). It is now accepted that the Leeuwin Current signature extends from North West Cape to Tasmania as the longest boundary current in the world (Ridgway & Condie, 2004).

There is general consensus that the driving force of the Leeuwin current is an alongshore geopotential gradient (also called steric height gradient). The source of the Leeuwin Current water is from the Indian Ocean from the west and a component from the North West continental shelf which originates from the Pacific Ocean. The South East Trade Winds, in the Pacific Ocean, drive the South Equatorial Current westwards advecting warm surface waters towards Indonesia. This results in the flow of warm, low-salinity water from the western Pacific Ocean through the Indonesian Archipelago into tropical regions of the Indian Ocean. The lower density water (lower salinity, warmer) in the north-east

Indian Ocean and higher density water (higher salinity, colder) off south-western Australia results in a surface slope between latitudes of 15º S and 35º S which is of the ~4 x 10^{-7} (from north to south), relative to the surface 0–300 dB level and corresponds to a sea level difference of 0.55 m between North West Cape and Cape Leeuwin.

During October to March the Leeuwin Current is weaker as it flows against the maximum southerly winds, whereas between April and August the Current is stronger as the southerly winds are weaker (Godfrey and Ridgway, 1985). This is reflected in mean sea level at Fremantle. Here, the sea level is higher between April and August when the Leeuwin Current is stronger (lower wind stress) and lower between October and January when the Current is weaker (high wind stress). Thus although the Leeuwin Current flows all year round, it exhibits a strong seasonality with the stronger flows occurring during the winter months (May - July). The location of the 'core' of the current also changes seasonally – in winter the core of the current located close to 200m contour whilst under the action of the southerly wind stress, the Current is pushed offshore (Figure 6.16).

The LC is weaker (~1.5 Sv; 1 Sv = 10^6 m^3s^{-1}) as it flows against the southerly (opposing) winds during October–March (summer) and stronger (7 Sv) when the southerly winds are weaker during April–September (winter) (Smith et al., 1991). The mean volume transport is estimated to be 3.4 Sv (Feng et al., 2003).

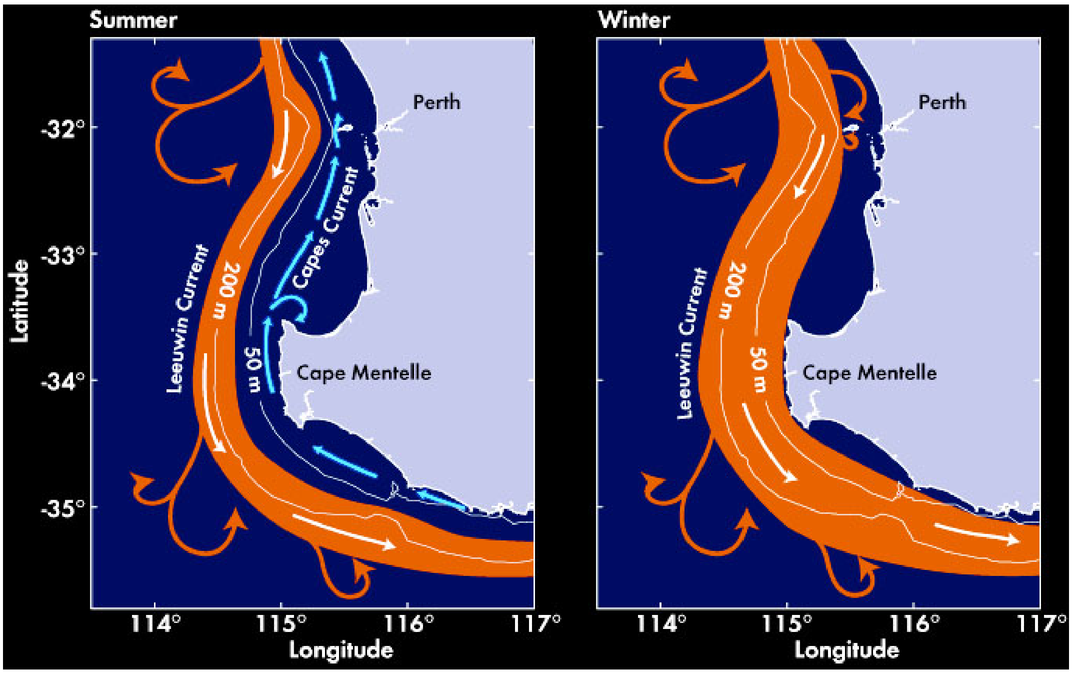


***Figure 6.17**: Schematic of surface currents off south-western Australia; during the summer the northward flowing Capes current is located on the inner shelf and bounded offshore by the Leeuwin current. In winter the Leeuwin current is located farther inshore (Hanson et al., 2006).*

The Leeuwin current is generally associated with mesoscale eddies and meanders (Pearce and Griffiths 1991; Fang and Morrow 2003; Morrow et al.

2003; Feng et al. 2005; Fieux et al. 2005; Meuleners et al. 2007; Rennie et al. 2007; Waite et al., 2007). Eddies form at the shelf break, separate from the current, and drift westwards. These eddies are apparent in sea surface temperature satellite imagery (Griffin et al. 2001) and altimeter data (Fang and Morrow 2003).
A major feature of the eddies are that extend through the water column to maximum depths of 2500 m (Fieux et al. 2005; Meuleners et al. 2007). The eddies have a lateral length scale ~ 220km and a mean propagation speed of 7 kmd^{-1} (Meuleners et al. 2007).

The Leeuwin current interacts with changes in the bathymetry and offshore water of different densities to generate and transport eddies offshore—in particular, off Shark Bay, the Abrolhos Islands, Jurien Bay, Rottnest Island, and Cape Leeuwin. The main eddy-generating regions influencing Vlaming Sub-Basin and Mentelle Basin are:

(1) South-west of Jurien Bay (29–30° S, 114–115° E). The eddies formed offshore Abrolhos Islands have a length scale ~200 km (Figure 6.1); the interaction between the eddies formed to the north and the coastline at Jurien Bay moves water offshore and generates eddies.
(2) Perth Canyon (32° S, 115° E). The Perth Canyon is the main topographic feature along the continental slope and traps eddies in the canyon. Rennie et al. (2007) examined the Leeuwin undercurrent's influence on eddy formation.
(3) South-west of Capes Naturaliste and Leeuwin (32° S, 115° E). At Cape Leeuwin (34–35° S; Figure 6.1), the coastal topography undergoes a 90° change in orientation: to the north, the flow along isobaths is directed to the south; to the south, the flow turns abruptly to the east.

Elevated chlorophyll values at the centre of an eddy have been attributed to the upwelling of colder, nutrient-rich waters enhancing production. Off the Western Australian coast, higher chlorophyll levels were found at the centre of cold-core eddies; however, the higher chlorophyll levels were due to the entrainment of continental shelf water into the eddies rather than upwelling at the eddies' centre. Analysing the satellite images (Pattiaratchi et al. unpublished) revealed three processes responsible for moving higher chlorophyll continental shelf water offshore:

(1) the Leeuwin current impinging on the continental shelf, partially entraining shelf water into its boundary
(2) the Leeuwin current flooding the shelf, thereby fully entraining (i.e. mixing completely with and absorbing) the shelf water
(3) unknown mechanisms, perhaps wind and topographic interactions.

The dynamics and primary productivity of eddies off the Western Australian coast have been studied over the past few years. Some of the earlier results are presented as a special issue of *Deep-Sea Research Part II: Topical Studies in Oceanography* (Waite et al., 2007). Here, the physical structure, primary production, and larval fish assemblages in warm-core and cold-core eddy are examined.

6.3.2 The Leeuwin Undercurrent

Initial studies by Thompson (1984, 1987) indicated that there was an equatorward undercurrent flowing beneath the Leeuwin Current (Figures 6.15 and 6.16). Current meter data from the LUCIE experiment (Smith et al., 1991) confirmed the observations of Thompson (1987) and indicated that the equatorward undercurrent was narrow and situated between 250 m and 450 m depth contours, adjacent to the continental slope. The Undercurrent transports 5 Sv of higher salinity (> 35.8), oxygen-rich, nutrient-depleted water at a rate of 0.32–0.40 ms^{-1} northward (Thompson, 1984; Woo and Pattiaratchi, 2008). Measurements indicate the current is stronger during November to January (Thompson 1984; Smith et al. 1991).

The LU is driven by an equatorward geopotential gradient located at the depth of the Undercurrent (Thompson, 1984; Woo and Pattiaratchi, 2008). The LU is closely associated with the subantarctic mode water (SAMW) formed in the region to the south of Australia. A feature of this water mass, resulting from convection, is high, dissolved oxygen concentration; thus a cross-section of the LU core can be identified from the dissolved oxygen distribution: the core of the current consists of a dissolved oxygen maximum (252 μM/L) centred at a depth of approximately 400 m (Woo and Pattiaratchi, 2008).

6.3.3 Flinders Current

The Flinders Current (FC) - the only northern boundary current in the Southern Hemisphere, is the dominant feature along the southern coast of Australia extending from Tasmania to Cape Leeuwin (Figure 6.15). The Current is driven by a positive wind stress curl (in both summer and winter) which results in northward transport (due to Sverdrup balance) centred along 135ºE which is deflected to the west to satisfy vorticity dissipation and mass conservation (Cirano and Middleton, 2004). The current is present in both summer and winter and the westward transport, between latitudes 37ºS and 39ºS, varies between 8 Sv and 17 Sv and is stronger during summer months (Figure 6.18). The current extends through the water column to a maximum depth of 800 m with maximum currents up to 0.5 ms^{-1} in the offshore region. The FC interacts with the Leeuwin Current (LC) at the shelf break and slope. Here, the LC is observable near the shelf break/slope as a surface current flowing eastward whilst the FC located as a subsurface current flowing westward. Comparison of temperature and salinity data collected along the south and west coasts indicate that the Flinders Current is the source of the Sub Antarctic Mode Water which forms the core of the Leeuwin Undercurrent (section 6.3).

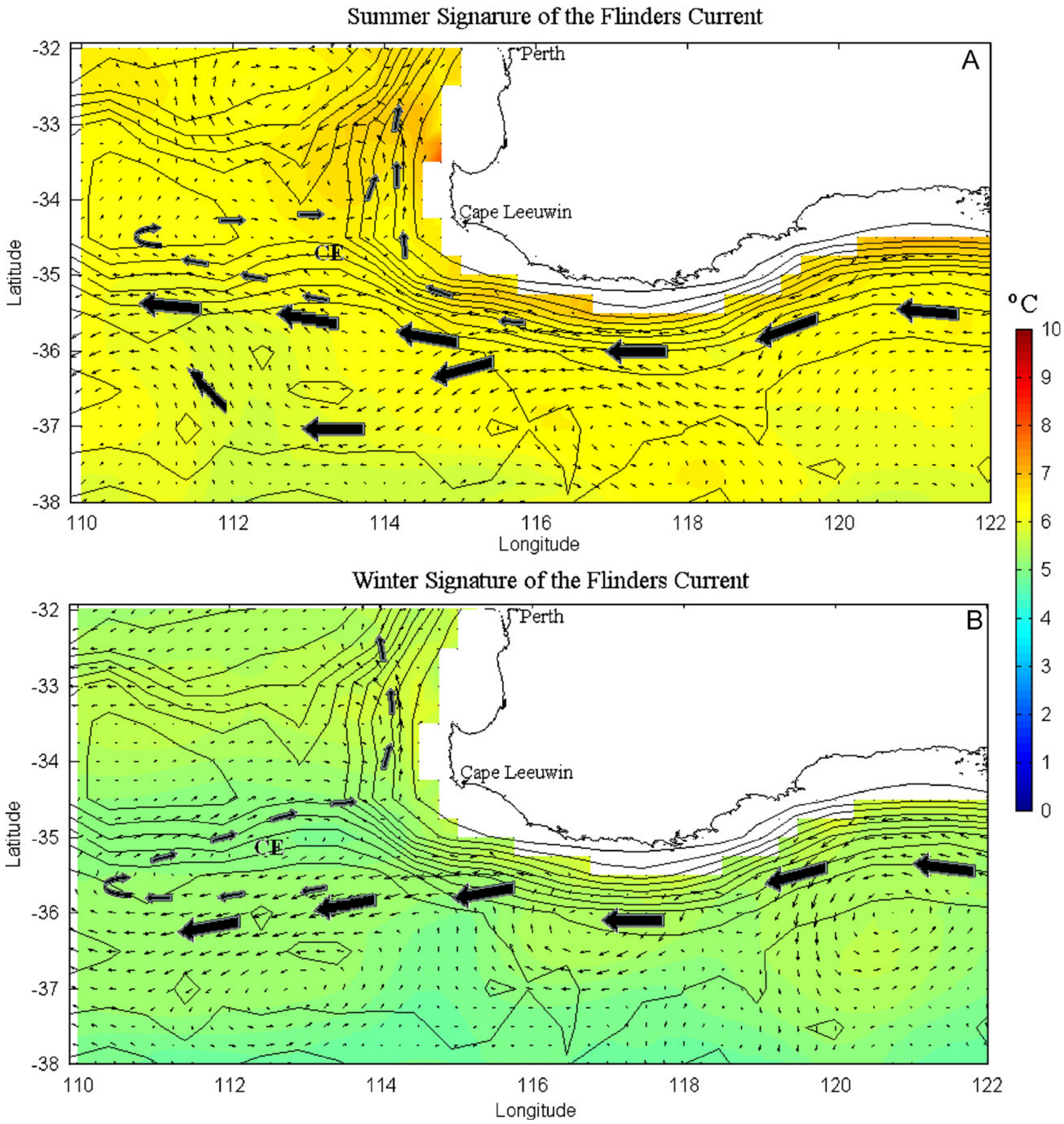


***Figure 6.18**: Numerical model results showing the showing (A)the mean composite summer (October–March) signature and (B) the winter signature (April–September) of the Flinders Current for years 1998–2001 (from Meuleners et al., 2007).*

6.3.5 The West Australian Current

Eastern boundary currents (EBC) occur along most eastern ocean boundaries as slow and broad equatorward currents (in contrast to the intensified poleward western boundary currents) forming one part of the anticyclonic subtropical gyre in each hemisphere's oceans. These gyres result from the Sverdrup balance: a balance between wind stress, pressure gradients and Coriolis acceleration. The

EBC regions are characterised by cooler (through upwelling) water and high primary productivity, thus supporting major pelagic finfish industries. Western Australia does not have the level of biological productivity induced by the Humboldt Current off Africa or the Benguela Current off Peru because the Leeuwin Current suppresses the upwelling of cooler, nutrient-rich water along the continental shelf.

The West Australian Current (WAC) is an equatorward surface current located offshore of the Leeuwin Current. Schott and McCreary (2001) postulated that the northward current extends westward from the Western Australian coast up to latitude 60^{o}E: a width > 1000 km (Figure 6.15). As is the case of eastern boundary currents, the WAC is shallow and completes the south-eastern arm of the subtropical Indian Ocean gyre similar to the large-scale anticlockwise motion in ocean basins (Tomczak and Godfrey, 1994). Andrews (1977) indicated that the WAC provides an eastern inflow to the LC at the approximate latitude 30 - 34^{o}*S*, turning south near the coast between 29 - 31^{o}S, particularly during the summer months. Recent studies have supported this finding, suggesting it enters further south at 30 - 33^{o}S, possibly being entrained in the poleward LC flow (Church *et al.*, 1989). It is possible that the inflow from the WAC increases the Leeuwin Current flow as it rounds Cape Leeuwin and proceeds into the Great Australian Bight (Cresswell and Peterson, 1993; Akhir and Pattiaratchi, 2008).

6.3.3 The Capes Current

Pearce and Pattiaratchi (1999) defined the Capes current as a cool inner shelf current, originating from the region between Capes Leeuwin (34° S) and Naturaliste, which moves equatorward along the south-western Australian coast in summer and extends northwards past the Abrolhos Islands. The Capes current seems to be well established around November, when winds in the region become mostly southerly because of the strong sea breezes (Pattiaratchi et al. 1997), and continues until about March when the sea breezes weaken. Gersbach et al. (1999) showed the Capes current source water was from upwelling between Capes Leeuwin and Naturaliste, which was augmented by water from the south to the east of Cape Leeuwin.

Gersbach et al. (1999) described the dynamics of the Capes current, off Cape Mentelle. The continental shelf in Australia's south-west comprises a step structure, with an inner shelf break at 50 m and an outer shelf break at 200 m (Pearce and Pattiaratchi 1999). This bathymetry influences the circulation, especially in the summer. In the summer, the alongshore wind stress overwhelms the alongshore pressure gradient on the inner shelf (depths < 50 m), moving surface layers offshore, upwelling colder water onto the continental shelf, and pushing the Leeuwin current offshore (Figure 6.19). Here, the Capes current is present on the inner shelf and bounded offshore by the Leeuwin current on the lower shelf, with upwelling occurring over the inner shelf break (Gersbach et al. 1999). Numerical model results showed a wind speed of 7.5 ms^{-1} was sufficient to overcome the alongshore pressure gradient on the inner continental shelf (Gersbach et al., 1999). The Leeuwin current strengthens in the winter, and, in the absence of wind stress, migrate closer inshore, flooding upper and lower terraces (Pearce and Pattiaratchi 1999).

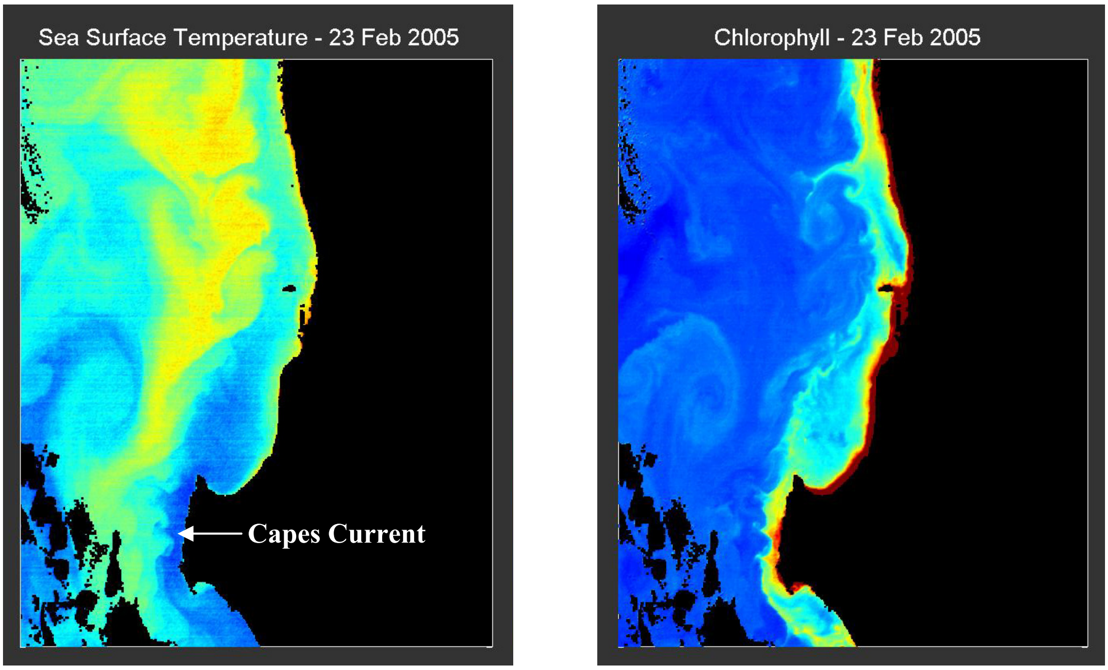


Figure 6.19*: Ocean colour images off south-western Australia showing the sea surface temperature and the upwelling of cold water onto the Capes current with the associated high chlorophyll concentration.*

Although the Capes current extends from Cape Leeuwin to past the Abrolhos Islands, the most intense upwelling, and therefore the highest concentration of surface chlorophyll a (Figure 6.18), occurs between Capes Naturaliste and Leeuwin, as the winds are strongest along this section of the coast compared with the north.

Gersbach et al. (1999) found water upwelled from the base of the Leeuwin current contained only slightly elevated nutrients (0.4 μM NO_3^-), compared with the bulk of the Leeuwin current (0.2 μM NO_3^-). In contrast, Hanson et al. (2005) upwelling in the Capes region transported higher nitrate concentrations (> 1.0μM) into the upper euphotic zone (< 50 m). The nutrients were sourced from the nutricline at the base of the mixed layer beneath the Leeuwin current. Hanson et al. (2005) found that because of the upwelling of higher nutrient water, seasonal upwelling in the Capes region supported high primary production rates. Maximum production rates were 945 mg C m^{-2} d^{-1}, with the higher depth averages produced at the 50-m contour. Hanson et al (2005) also found that in winter, the stronger Leeuwin current flow, and its interaction with the shelf water upstream of the Capes region, increased the nutrient levels (nitrate levels of ~2–3μM) in the Capes region; however, compared with summer, the lower subsurface light conditions (lower solar angle and higher attenuation due to storm action) in winter lowered the primary production.

6.3.4 Upwelling

The Leeuwin current's presence promotes an oceanic environment that supports downwelling in the continental shelf and break region along the west Australian coast. The combination of the alongshore pressure gradient (the Leeuwin current's driving force) and the Coriolis force transports water onshore, causing downwelling. The prevailing southerly winds, especially in the summer, have the opposite effect: the combination of the wind stress and the Coriolis force moves water offshore, causing upwelling along the continental shelf. Thus the resulting circulation depends on these two processes competing. In general, the alongshore pressure gradient dominates, causing downwelling. Under strong wind conditions, however, the wind effects can dominate, causing upwelling.

One such region where this process—termed here as the 'Cape Mentelle upwelling'—occurs is between Capes Leeuwin and Naturaliste in the south-west corner of Australia. The Capes current also originates from this region (see section 6.6).

Another region of upwelling is within the Perth canyon. The interaction between shelf and slope current systems causes localised flow patterns, which influence the ecology in the canyon vicinity. Compared with their nearby surroundings, submarine canyons have higher biodiversity and biological productivity (Hickey 1995). This is often attributed to upwelling at the canyon site enriching the photic zone with nutrients. The Perth Canyon is an extension of the Swan River system, and cuts into the continental shelf west of Perth and Rottnest Island within the Mentelle sub basin. The Perth Canyon, which starts at the 50-m contour, is ~100 km long and ~10 km wide near the canyon head, and reaches depths more than 1000 m. It is 3 km deep at the shelf slope, and cuts 4 km deep into the continental slope. The canyon "head" refers to the canyon's shoreward section, and the "tip" refers to the head's closest point to the coast. The canyon bends at 10 km and 50 km from the tip, and branches south at 40 km and 50 km. At the canyon head, the depth plunges from 200 m to 1000 m, with the canyon mouth opening onto the abyssal plain at a depth of 4000 m. Hence the Perth Canyon can be described as long, deep, narrow, steep-sided, and intruding into the continental shelf.

Rennie et al. (2007) have demonstrated that the Leeuwin undercurrent interacting with the canyon generated eddies within the canyon (Figure 6.20). These eddies, which were formed over periods of five to ten days, migrated offshore, and other eddies would form in the canyon. The eddies were clockwise, and thus favoured upwelling at their centre. Eddies sometimes recurred within the canyon, suggesting the canyon regulated the circulation, with several circular eddies present, both spatially and at different depths, in the canyon at any given time. Eddies formed in the canyon were first confined to the canyon and then migrated offshore; however, at least one eddy, even if it was weak, was present in the canyon at any given time. As a result of these circulation patterns within the canyon, the canyon supports a high primary and secondary production resulting in the whale (pygmy blue whales) aggregation during the summer months (Rennie et al., 2007).

Eddies caused regions of upwelling or downwelling, with deep upwelling stronger in the canyon than elsewhere on the shelf. Near-surface vertical transport was strong everywhere when wind forcing was present. The circulation in the canyon contributed to upwelling and downwelling, and produced upwelling to above 300 m, mainly at the head and along the canyon rims. Upwelling alone was insufficient to transport nutrients to the euphotic zone because the canyon rims are deep. Increased upwelling, combined with entrapment within eddies and strong, upwelling-favourable winds caused the high primary productivity in the canyon. The Leeuwin current formed a strong barrier to the water upwelling to the surface. The model results also suggested upwelling at the canyon head occurred when a clockwise surface eddy was centred over the south rim, whereas an eddy (either clockwise or anticlockwise) centred on the north rim caused net downwelling (Figure 6.20).

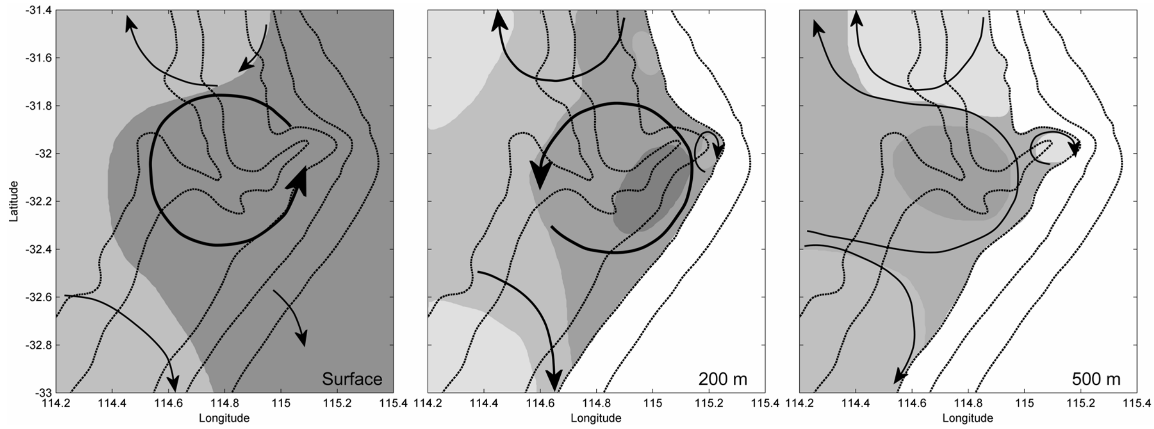


***Figure 6.20**: Example flow patterns in the Perth Canyon at the surface, 200 m, and 500-m depths. Shading indicates temperature, with lighter shades showing the upwelling regions (from Rennie et al., 2008).*

6.3.5 Coastal-trapped waves

A coastally trapped wave is defined as a wave that travels parallel to the coast, with maximum amplitude at the coast and decreasing offshore. Examples of these waves include continental shelf waves (CSWs) and internal Kelvin waves (Le Blond & Mysak 1978), which are governed through vorticity conservation (Huyer 1990). Coastally trapped waves need a shallowing interface and may develop a range of modes according to the shelf structure (Tang & Grimshaw 1995). They travel with the coast to the left (right) in the southern (northern) hemisphere. Along the Australian coast, shelf waves propagate anti-clockwise relative to the landmass. All these wave types propagate along the coastal boundary, with the wave signal reducing in amplitude with distance offshore.

Continental shelf waves (CSWs) depend on only the cross-shelf bathymetry profile, and the vertical density profile controls the structure of an internal Kelvin wave (Huyer 1990). The alongshore component of wind stress usually generates CSWs, which are common along the Australian coast. Analysis of water levels from southwest Australia, first reported by Hamon (1966), has revealed a number of significant tidal residuals that were not fully explained by local synoptic conditions. Further examination of the composition of the coastal surges suggests that it was comprised of a combination of locally generated (through local changes in atmospheric pressure and local wind field) and remotely generated signals. The remote signal was characteristic of a long period coastally trapped shelf wave, generated by up to thousands of km to the north and translated southward along the coast. Provis & Radok, (1979) demonstrated that these waves propagate anti-clockwise along the Australian continent over a maximum distance of 4000 km at speeds of 5–7 ms^{-1}.

Along the West Australian coastline, the continental shelf waves are generated through the passage of frontal systems and tropical cyclones. The continental shelf waves are identified in the tidal records by low-pass filtering (i.e. removal of the tidal component). An example is shown on Figure 21 for tidal records from Geraldton, Fremantle and Albany. Several continental shelf waves (CSWs), with amplitudes ranging from 0.1 to 0.5 m can be identified. For example, between days 290 and 295, an increase of ~0.5 m in the sub-tidal water level was observed at Geraldton. The same variation in water level signal was seen at Fremantle and Albany, and could be attributed to the passage of a CSW. The correlation coefficients between sub-tidal water levels at these three locations were all greater than 0.8, despite observations being several hundred kilometres apart. The propagation time of the CSW between Geraldton and Fremantle was 23 hours, and between Fremantle and Albany it was 17 hours, yielding a mean propagation speed of ~500 km day^{-1} (~6 ms^{-1}). The period of the continental shelf wave range between 3-10 days and corresponds to the passage of storm systems from west to east across the west Australian coastline.

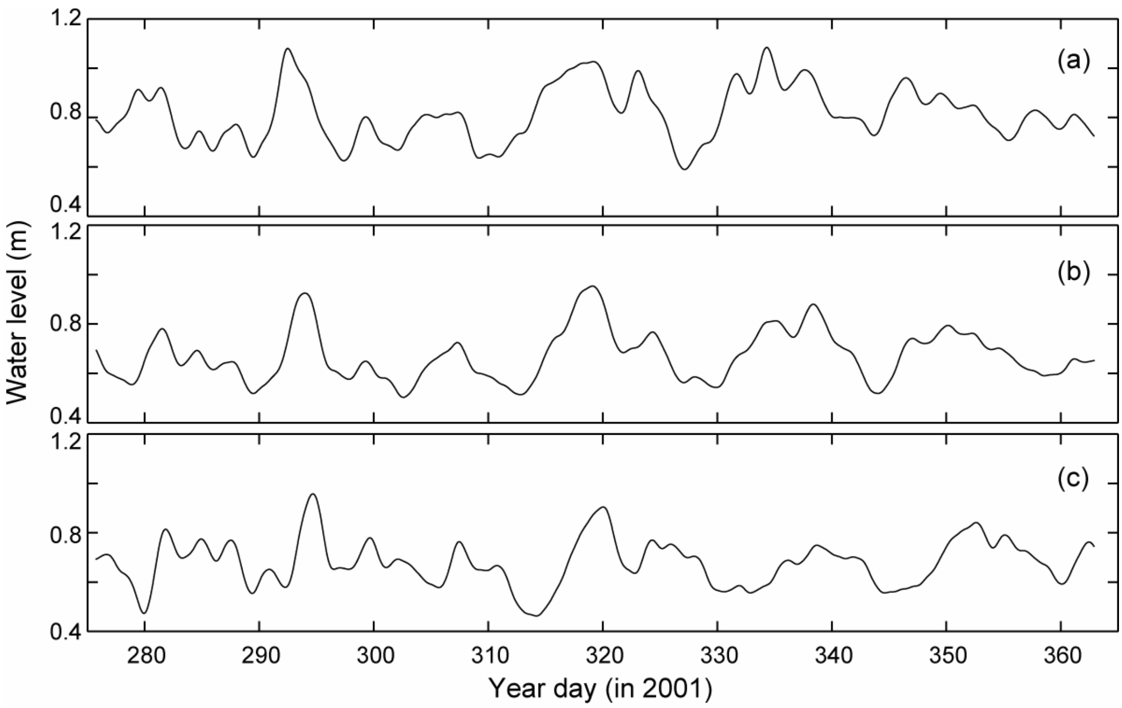


***Figure 6.21**: Low-frequency water levels at (a) Geraldton, (b) Fremantle, and (c) Albany for days 275 to 365 in 2001 showing the presence of continental shelf waves (from O'Callaghan et al., 2007).*

6.4 TIDES

Astronomic tides are the most widely recognised phenomena affecting water levels. These tides are the harmonic fluctuations of water level developed through the gravitational attraction from astronomic bodies (mainly the sun and moon). The tides at Bunbury tide station is representative of the tides experienced along south-western Australia. The four largest constituents are associated with diurnal and semidiurnal effects of the sun and moon (Table 6.2). The relative position of the sun and moon develops a monthly cycle of enhanced (spring) and lowered (neap) tidal ranges as the principal constituents move in and out of phase.

Table 6.2: Principal tidal constituents for Bunbury

Constituent	Amplitude	Period (hr)	Description
K_1	0.173	**23.93**	Principal lunar diurnal constituent
O_1	0.120	25.82	Principal solar diurnal constituent
M_2	0.057	12.42	Principal lunar semidiurnal constituent
S_2	0.053	12.00	Principal solar semidiurnal constituent

South-western Australia experiences a mixed, micro-tidal, mainly diurnal climate, with an astronomic tidal range of 1.2 m. The daily tidal range varies biannually, with solstice tidal peaks occurring around December–January and June–July, producing a monthly tidal range that is about 20% higher than during equinoctial troughs during February–March and September–October. A large, seasonal mean water level signal also occurs, with a 0.22-m average annual range, peaking in June and lowest in November (Pariwono et al. 1986; Pattiaratchi & Buchan 1991). The combined effect of the seasonal tidal cycle and annual mean sea level cycle produces short periods, which include high and low water levels during May–June and December–January, respectively.

Along south-western Australia, the tide's diurnal component has a range of 0.6 m, and the semidiurnal tide has a range of only 0.2 m. The semidiurnal tidal range is related to the lunar cycle, with the maximum tidal range occurring close to the full and new moons, and minimum tidal ranges occurring close to the lunar cycle's first and last quarters—the spring–neap cycle. Diurnal tides are related to the declination angle of the moon's orbital plane. The diurnal and semidiurnal tides oscillate at a frequency of 13.63 and 14.77 days, respectively. This phase difference, of 1.14 days, between the two tidal signals modulates the resultant tide over an annual cycle, causing the diurnal and semidiurnal tides that are in phase during the solstice (resulting in a maximum "spring" tidal range) and out of phase at the equinox (resulting in a minimum "spring" tidal range). This means the highest tidal range (the "spring" tide) does not always correspond with the full/new moon cycle.

During the solstice, when the diurnal and semidiurnal tides are in phase, the maximum tidal range corresponds with the full/new moon cycle; during the equinox, the maximum tidal range does not correspond with the full/new moon cycle. Mixed tides occur during "neap" tides closest to the equinox, with two high and low waters commonly observed over a tidal cycle. Hence, in a diurnal tidal system, such as along south-west Australia, definitions such as *spring* and *neap* tides do not always relate to phases of the moon, as is the case for semidiurnal tides.

Another consequence of the diurnal tides is the seasonal change in the times of high/low water. During the summer, the low water generally occurs between 4 am and 12 pm, depending on the phase of the moon, with high water in the evening. As summer progresses, the low water occurs earlier; as winter starts, the low water occurs later at night, becoming progressively earlier in the evening (with high water occurring in the morning).

6.5. WINDS

The weather systems along south-western Australia are dominated by anti-cyclonic high-pressure systems with periodic tropic and extra-tropical cyclones (mid-latitude depressions) and local seasonal sea-breezes (Eliot & Clarke 1986). Anticyclones move to the east and pass the coast every 3-10 days (Gentilli 1972). The location of the anti-cyclonic band migrates from around 38ºS in summer, generating mainly offshore winds, to around 30ºS in winter, producing mainly onshore winds (1972). Mid-latitude depressions interrupt the prevailing weather in winter with initial northerly winds, freshening and shifting to north-westerlies, then moving rapidly to westerlies and south-westerlies as the system crosses the coast (Lemm et al., 1999; Masselink & Pattiaratchi, 2001a). The peak occurrence of mid-latitude depressions is in July and the strongest winds in the system are the north-westerlies (Gentilli, 1971; Lemm et al., 1999). These weather systems generate south-westerly cold fronts (Gentilli, 1971). Tropical cyclones track down from the Northwest coast infrequently during late summer and can have significant impact on the coastline (Eliot & Clarke, 1986; Lemm, 1996). The seasonal movement of the high-pressure systems results in a strong seasonality in the wind regime (Figure 6.22). During the summer southerly winds prevail whilst in winter dominant wind direction although the strongest winds are north-westerly occurring during the passage of frontal systems. However, the direction of the winds changes rapidly through the passage of the storm.

Sea breezes, which are stronger during the summer dominate the coastal region including the Mentelle sub basin, with offshore (westward) winds in the morning and strong (up to 15 ms^{-1}) sea breezes commencing around noon and weakening during the night (Pattiaratchi et al., 1997). Unlike the ‘classic’ sea breeze, these sea breezes blow parallel to the coastline; their onset is rapid, initial velocities are relatively high, and the surface currents respond almost instantaneously (Pattiaratchi et al., 1997).

During winter, the region is subject to the passage of frontal systems, and ~30 storm events are experienced (Lemm et al. 1999). During the passage of a frontal system, the region is subject to strong winds (up to 25–30 ,ms^{-1}) from the north-west, which rapidly change direction to the west then south-west over 12–16 hours. The south-westerly winds gradually weaken over two to three days, and calm, cloud-free conditions prevail for another three to five days before the passage of another frontal system.

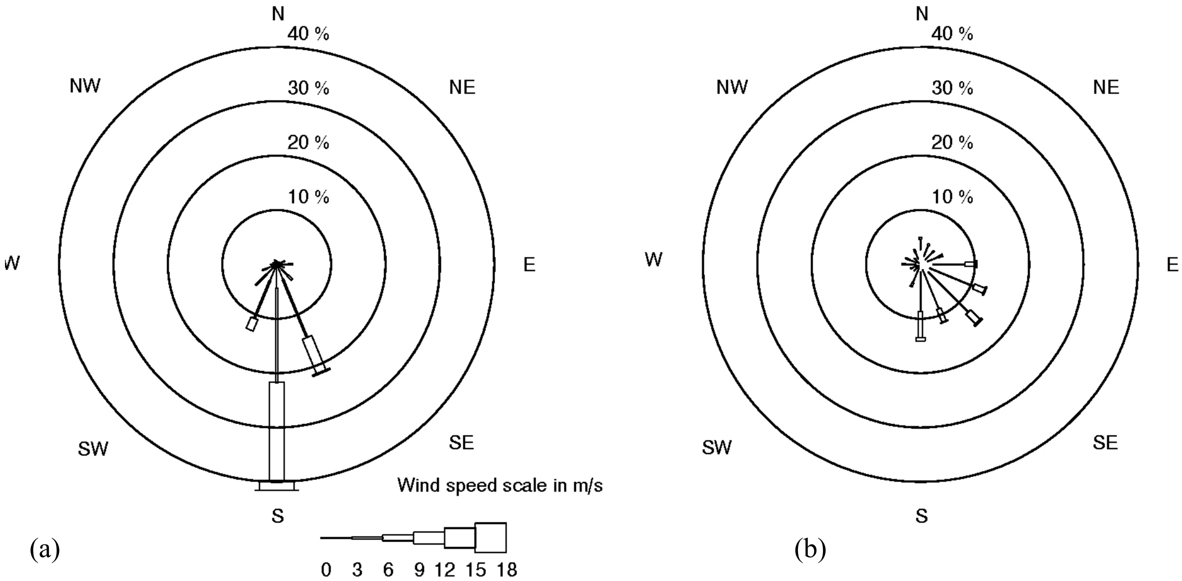


***Figure 6.22**: (a) Summer and (b)winter wind roses for winds recorded at Rottnest Island showing the highly seasonal nature of the wind regime in the region.*

The mean wind speed, direction, duration, extremes and event frequency for the main weather systems experienced on the Perth Metropolitan Coast are presented in Table 6.3.

Table 6.3: Winds and event frequency for the major weather systems incident on south-western Australia.

Weather System	*Anticyclones*	*Squalls*	*Mid-latitude depression*	*Dissipating tropic cyclones*	*Sea breeze*
Occurrence	Annual	Dec – April	May – Oct	Oct – Mar	Oct – Mar (significant)
Avg. Wind Speed	Light winds	15 – 20 ms^{-1}	15 – 29 ms^{-1}	15 – 25 ms^{-1}	10 ms^{-1}
Avg. Duration	Unknown	2 – 4 hours	10 – 55 hours	5 – 15 hours	~7 hours
Avg. Wind Direction	All	All	N → NW → W → SW	Depends on eye location	180 - 200°
Frequency	3 – 10 days	13 days	Avg. 3 – 8/year	1 in 10 years	>15 days/month
Extreme 30 Min. Avg.	Unknown	25 ms^{-1}	20 – 25 ms^{-1}	25 – 30 ms^{-1}	> 20 ms^{-1}
References	(Gentilli 1971; 1972)	(Steedman 1982; Eliot & Clarke 1986)	(Gentilli 1971; Silvester 1976; Steedman 1977; 1982; Lemm et al. 1999)	(Gentilli 1971; Steedman 1977; 1982)	(Gentilli 1971; Masselink 1996; Pattiaratchi et al. 1997)

6.5 WIND WAVES

The maximum water depth to which waves influence the seabed is equal to half the wavelength and significant influence on the seabed is limited to depths less than one-quarter of the wavelength. The deep water wavelength *L* can be estimated using $L = \frac{gT^2}{2\pi}$ where g is gravitational acceleration and T is wave period (e.g. Wright, 1995). Even for the longest period swell waves, ca. 15 s, the wavelength would be 350 m, and thus the maximum depth to which the seabed would be even marginally influenced by waves is 175 m. Water depths across the Vlaming Sub-Basin s are typically >>200 m, thus the seabed in the region will not be influenced by waves. Nevertheless, waves will have an impact on shipping, platforms and any sea-surface operations associated with potential exploration and production in the area. In contrast, Mentelle sub-basin is generally < 200m and thus will be greatly impacted by the effects of waves.

Long-term wave data (> 10 years) from two stations are available from the region (Table 6.4).

Table 6.4: Locations on the southern margin of Australia for which wave information is available and periods for which analysis have been undertaken both in this report and Hemer et al. (2008).

Location	Longitude	Latitude	Water depth (m)	Analysis period
Cape Naturaliste	114° 47′ E	33° 22′ S	50	07/11/1998 to 31/12/2006[1]
Rottnest Island	115° 24′ E	32° 7′ S	50	25/07/1991 to 31/12/2006

[1] Directional wave data for the past 3 years

The offshore wave climate in the region is dominated by moderate energy swell from the south to southwest, and a variable wind wave climate is superimposed on the background swell (Masselink & Pattiaratchi, 2001). Sea breezes have a strong influence on the offshore wave conditions during summer, therefore the prevailing wave direction is south to southwest (Figure 6.23). Offshore waves during summer have predominantly low period (less than 8 s) in the range of 1-2 m (Lemm, 1996). Northwesterly to southwesterly storm waves occur during the winter months, and the offshore wave climate is characterised by high period (more than 8 s) swell and storm waves of 1.5-2.5 m (Lemm, 1996). Hence, for the study area, there is a distinctive offshore wave climatic shift from moderate, locally generated seas in summer to higher, distantly generated swell in winter (Lemm, 1996). A background swell above 0.5 m was found to be present all year round (Lemm, 1996). The wave climate also exhibits strong inter-annual variability (Figure 6.24).

Wave data from Rottnest, obtained from the analysis of 5 years (1994 – 1998) data indicated that the mean significant wave height was 2.0 - 2.2m and the mean wave period was 8.8s (Lemm et al., 1999; Masselink & Pattiaratchi, 2001a). During this period, the mean summer and winter significant wave heights were 1.8m and 2.8m respectively, and the mean periods as 7.6s and 9.7s respectively. Longer wave periods were generally associated with summer swell. The mean summer wave period is shorter due to the superimposition of shorter period sea-breeze waves.

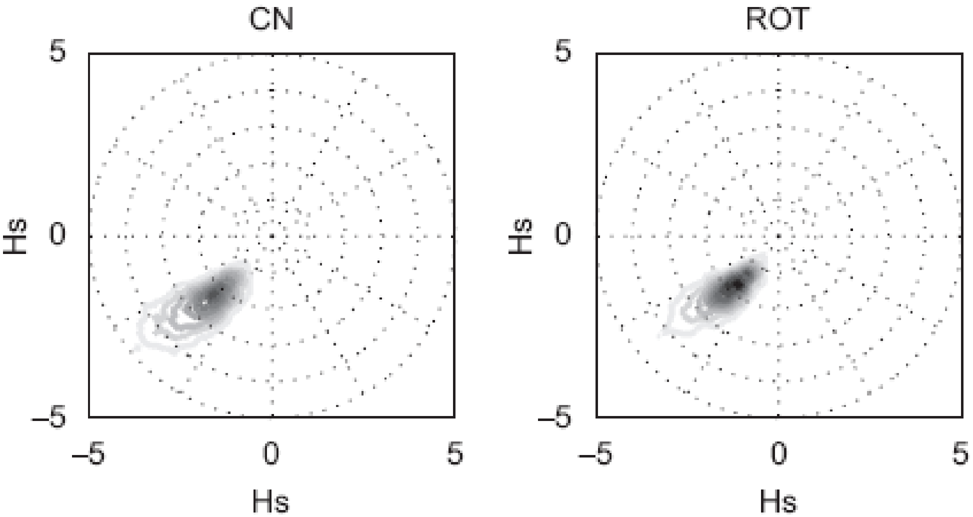


Figure 6.23: *Rose plots of peak wave direction (angle of approach) versus the significant wave height (m) at Cape Naturaliste (CN) and Rottnest Island (ROT) (after Hemer et al., 2008).*

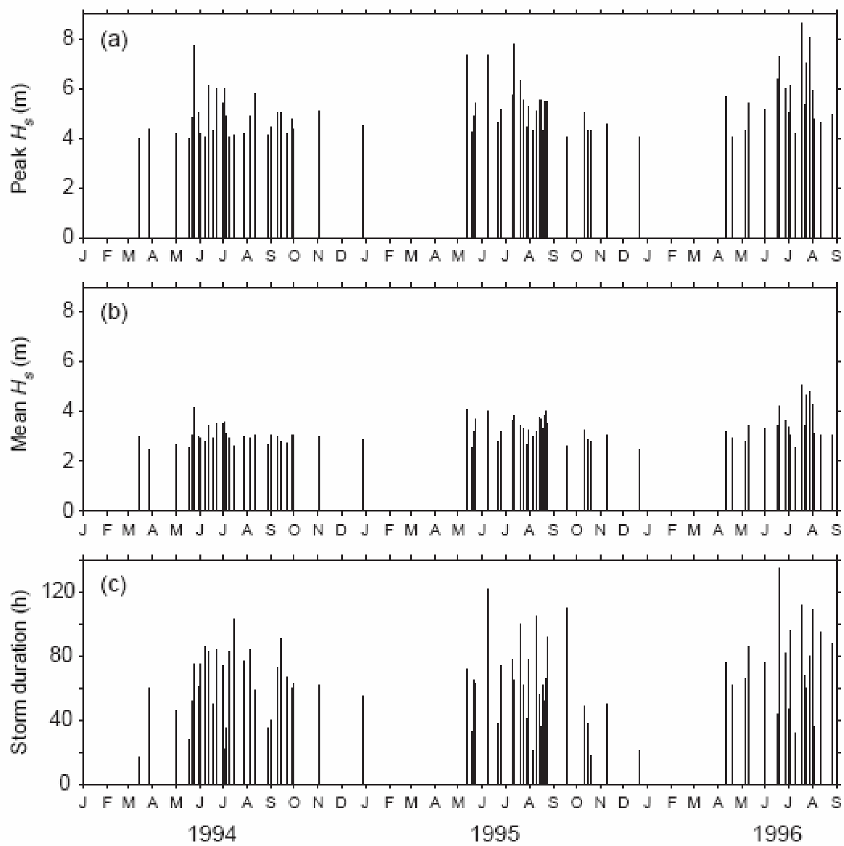


Figure 6.24 *- Temporal distribution of storms offshore from Perth: (a) storm peak Hs; (b) storm mean Hs; and (c) storm duration (from Lemm et al., 1999).*

Locally generated waves are dominated by storms and the sea breeze. In the coastal region, the presence of the sea breeze in summer shortens the wave periods as the mean wave period for the sea breeze component is 4 – 6s (Pattiaratchi et al., 1997). The seas produced by the sea breeze have significant wave heights of 1 – 2m with energy that can exceed prevailing swell (Pattiaratchi et al., 1997). Sea breeze waves are fetch- and duration-limited as the offshore extent of the system is 100km and the winds persist for approximately seven hours (Masselink 1996). Local winter cold fronts and mid-latitude depressions can produce seas where significant wave height is greater than 4m and can exceed 7m, with periods between 6 and 10s (DPI, 2004).

Mean annual, summer and winter wave heights are presented in Table 6.5, along with the extreme wave heights determined by the DPI (2004). Extreme analysis was applied for data from 1994 – 2003, updating the study by Lemm et al. (1999) which was applied for 2.5 years of data. The 1:100 recurrence intervals for the significant wave height for Rottnest (depth 48m) is 10.3 m.

Table 6.5: Mean Hs and Average Return Interval H for Rottnest and Cottesloe (Stul, 2005).

Average Return Interval of Wave or Height or Mean Hs	Rottnest (m)	Cottesloe (m)
Mean annual Hs	2.2	0.8
Mean winter Hs	2.8	1.1
Mean summer Hs	1.8	0.75
1 year	7.4	3.1
5 years	8.2	3.4
20 years	8.6	3.7
50 years	9.8	3.9
100 years	10.3	4.0

6.6 OCEANIC CONNECTIVITY

The interconnectedness of locations in the ocean has relevance to the geographic range of species and to endemism, developmental life-cycles for particular species, food supply etc. The Vlaming and Mentelle sub regions are located in a region which may be considered to be a confluence of several current systems.

The Vlaming Sub-Basin is influenced by the Leeuwin and Capes Currents. The Leeuwin Current originates from the north-west shelf region of Australia with the source waters coming through the Indonesian archipelago from the Pacific Ocean. Although the Capes current is postulated to start between Capes Naturaliste and Leeuwin its waters are supplemented by the westward flowing Cresswell current along the south coast (Figure 6.15) which in turn has its origins more to the east – perhaps as far as the Great Australian Bight.

The Mentelle sub region is influenced by the Flinders and West Australian Currents (Figures. 6.15 and 6.18). The Flinders currents has its origin off Tasmania and flows westward and off Cape Leeuwin, the current branches in to arms: one flowing northwards as the Leeuwin Undercurrent as far as the northwest shelf whilst the second flowing westward past the Naturaliste plateau, particularly during the summer months when the current is stronger (Figure 6.15).

Large scale oceanographic processes such as circulation provide connectivity between different regions. By examining the current magnitudes and duration and assuming that biota advect in the similar manner to parcels of water, the following time scales can be obtained for the different current systems/processes:

- The Leeuwin Current may advect water ~1500 km over a 1 month period.
- The Capes Current may advect water ~500 km over a 1 month period.
- The Flinders Current may advect water ~1300 to the west over a 1 month period.
- Coastal-trapped waves may advect water 80-100 km back and forth over a period of 10 days along the continental shelf

A detailed analysis of connectivity with due consideration to specific biota is beyond the scope of this report.

6.7 SEABED DISTURBANCE

In this report seabed disturbance refers to the potential for bed sediment to be mobilised or significant changes in bed elevation to occur through bedform migration. Processes that potentially cause seabed disturbance include bed shear from waves, tides and oceanic currents, as well as mass-movement due to slope failure and associated gravity currents. As already noted, water depths over the Mentelle sub basin are too large for any significant impact of wind waves on the seabed and tidal currents are weak (Sections 6.4 and 6.5). In contrast, the Vlaming Sub-Basin would be subject to the action of wind waves, except for the region of the Perth Canyon. Filed observations have indicated the presence of wave driven bedforms in this region confirming the competency of the waves to initiate and transport near bed sediments.

Maximum near bed currents obtained from a 3D numerical model run over a 6 month period are shown on Figure 6.25. The model was forced using winds and density gradients and therefore included the effects of the Leeuwin Current, Leeuwin Undercurrent and wind driven shelf current system (Capes Current). The maximum currents (0.6 ms^{-1}) occur along the continental slope at depths of 200-300 m where the Leeuwin Current has a direct influence on the sea bed. In the Mentelle sub-region maximum currents (0.4 ms^{-1}) occur on Naturaliste plateau most like to due to the influence of Flinders Current and Leeuwin Current eddies.

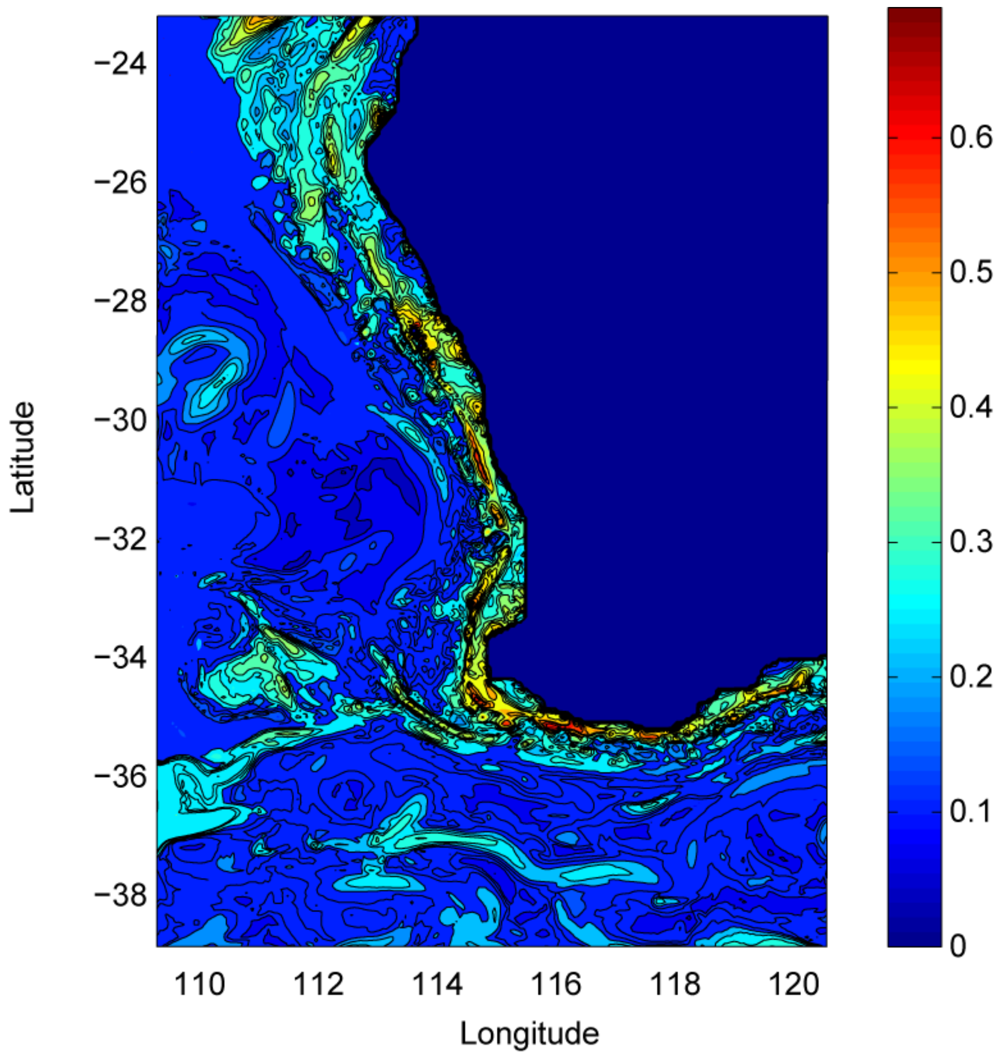


Figure 6.25 *– Maximum near-bed currents predicted using a 3D numerical model (from Michael Meuleners, UWA).*

6.8 SUMMARY

The Vlaming Sub-Basin and Mentelle Basin located off south-western Australia are subject to different and contrasting oceanographic processes. The Vlaming Sub-Basin is located in relatively shallow waters < 200m depth except for the Perth Canyon where the water depths are much higher. This means that the Vlaming Sub-Basin is influenced by continental shelf processes such as wind, waves, continental shelf waves and major current systems such as the Leeuwin and Capes Currents. In contrast, the Mentelle sub region is located in water depths > 1000 m and is therefore influenced oceanic current systems such as the Flinders and West Australian Currents.

7. Ecology

7.1 INTRODUCTION

This section summarises the available information on the ecology of Mentelle Basin and Vlaming Sub-Basin within the west coast bioregion. The first half of the chapter focuses on current human use of the region: marine protected areas, shipping lanes, and commercial fisheries. The second half of the chapter concentrates on biological knowledge of the area, beginning with regional biological patterns of the West coast bioregion, and then focusing on specific ecological facts known about Mentelle Basin and Vlaming Sub-Basin through surveys and biogeographical databases. Targeted areas for future research in the area are also identified, as well as potential considerations for future activities in these areas.

7.2 OVERVIEW OF THE WEST COAST BIOREGION

The west coast of Australia covers an expansive coast line (20,781 km) with 12.6 million hectares of water governed under state jurisdiction, and has 18 bioregions that govern marine activities and resources. Mentelle Basin and Vlaming Sub-Basin lie in the south western region of the state and fall within the Department of Fisheries 'west coast bioregion' (Figure 7.1). The west coast bioregion, which extends from Kalbarri (27^{o} S) in the north to Augusta (115^{o} E) in the south, is broadly comparable to the Interim Marine and Coastal Regionalisation for Australia report (IMCRA Technical Group 1997) except the Gascoyne coast is treated by the Department of Fisheries as a separate management region, while IMCRA have divided the region into three additional meso-scale regions: the Abrolhos Islands, the Central West Coast and Leeuwin–Naturaliste, while (Fletcher and Head, 2006). Although Mentelle Basin lies within IMCRA's southwest transition bioregion, Vlaming Sub-Basin falls across all four IMCRA boundaries within this region. In this chapter we describe the general ecology of the region using the definition of the west coast bioregion as this is the one used to manage and report on all coastal and offshore fisheries under both state and commonwealth legislation.

The waters in the west coast bioregion are temperate with surface temperatures ranging from 18 – 24° C (Pearce et al., 1999) resulting from the strong influence of the Leewin current that transports warm tropical waters down the west coast from the north. The delivery of these warm waters enables the growth of diverse and abundant coral communities much farther south than otherwise expected (Wilson and Marsh, 1980), and enables temperate seagrass meadows to flourish in nearshore areas (Kirkman and Kuo, 1990). The west coast region also lies at the interface between northern tropical and southern cool temperate systems and therefore supports a broad biogeographic overlap of tropical and temperate species (Wilson and Marsh, 1980).

Coastal and oceanic waters in this region are very clear as low amounts of terrigenous sediments are exported into the marine system (Collins, 1988). This combined with the presence and strength of the Leewin current that prevents the deep cold nutrient-rich waters from upwelling onto the coast, result in low levels of productivity across the west coast (Section 6). The overall low productivity of the region in turn supports exceptional high biodiversity, but low biomass, and small commercial fisheries relative to other regions of Australia (Ward and Rainer, 1988; Rainer, 1991; Williams et al., 2001).

The geological history of the region that has shaped the physical characteristics of the seafloor has important effects on the types of geophysical habitats and environments found in this region and the associated life there. In the deeper zones of the continental shelf and slope extensive deepwater benthic environments are present that include one of the most canyon-rich areas and largest abyssal plains of the Australian margin. These canyons may greatly alter local hydrology. For example, localised upwelling in the Perth Canyon increases local productivity that supports large krill populations and provides an important feeding ground for blue whales (Rennie *et al.*, 2006). However, compared to other environments, these deep offshore regions, particularly the deep basins, have received very little attention.

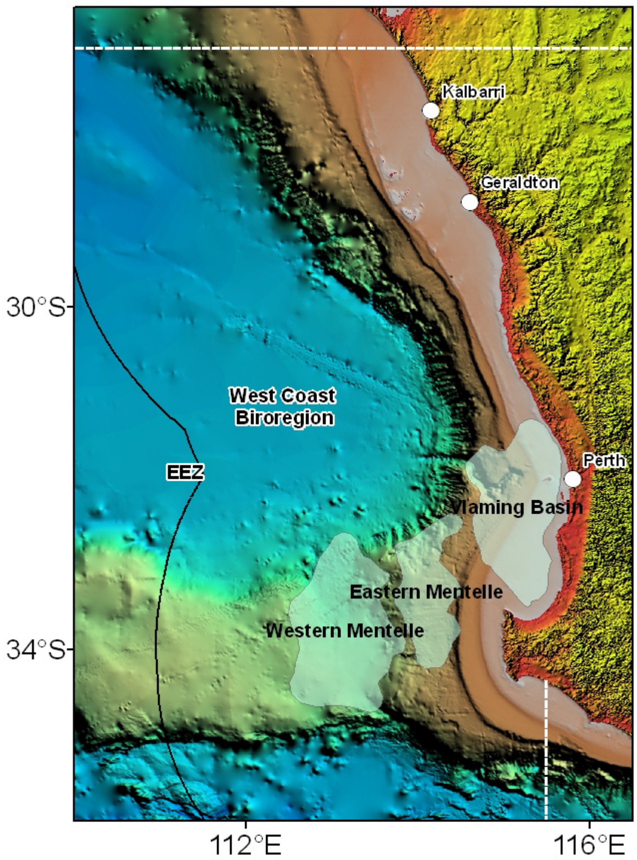


***Figure 7.1:** Map of the west coast bioregion showing the location of Mentelle Basin and Vlaming Sub-Basin (blue shaded polygons). Dotted lines mark the northern and southern boundary of the west coast bioregion.*

Recent surveys of the continental shelf and slopes off Western Australia (CSIRO and GA *unpublished reports*) characterized these environments as having fine sediments, with a gradient of coarse sands on the shelf to fine sandy mud on the slopes, and limited amounts of exposed limestone ridges and reefs mostly in areas of high slope, such as on canyon walls (Sections 4, 5). The fauna and flora of shelf and slope habitats along Western Australia are highly diverse, but low in biomass compared to those along the eastern coasts (Williams et al., 2001).

The offshore pelagic environment is also important for the larval dispersal of many coastal and deep-sea species. The movement of the long and narrow Leeuwin current from sub-tropical to temperate areas of Western Australia provides an important and predictable vector (often termed the '*conveyor belt*') for the latitudinal movement of species particularly dispersing larvae of many benthic and pelagic species, including many commercially important species (e.g. rock lobsters, scallops, prawns, pilchard), as well as a variety of other species (e.g. newly-hatched turtles) (e.g. Phillips and Pearce, 1997).

7.3 CURRENT USE OF THE WEST COAST BIOREGION

7.3.1 Marine Protection zones

Although there are eight marine parks and three fishery habitat protection areas located within the west coast bioregion (listed below) there are none in or adjacent to or that affect the Vlaming Sub-Basin and Mentelle Basin (Figure 7.2a). These MPA and FHPA designations are located along the coast of Western Australia, with the exception of the Abrolhos Island FHPA located 70 km offshore of Geraldton. The major threat to biodiversity and fish in these inshore habitats is from coastal development and environmental degradation of coastal and estuarine waters. The Mentelle Basin is located offshore in continental slope habitats and as such is unlikely to be directly affected by coastal activities and protection zones. However, the Vlaming Sub-Basin is much more likely to be subject to a range of coastal activities as it lies inshore of Mentelle (Figure 7.1) and includes inner shelf and coastal habitats.

Marine Parks and Reef Protected Areas (RPA) - *(all coastal)*

- Jurien Marine Park
- Marmion Marine Park
- Swan Estuary Marine Park
- Shoalwater Islands Marine Park
- Quindalup Artificial Reef RPA
- Swan Wreck RPA
- Yallingup Reef RPA
- Cowaramup Bay RPA

Fishery Habitat Protection Areas (FHPA):

- Abrolhos Islands FHPA
- Lancelin Island Lagoon FHPA
- Cottesloe Reef FHPA

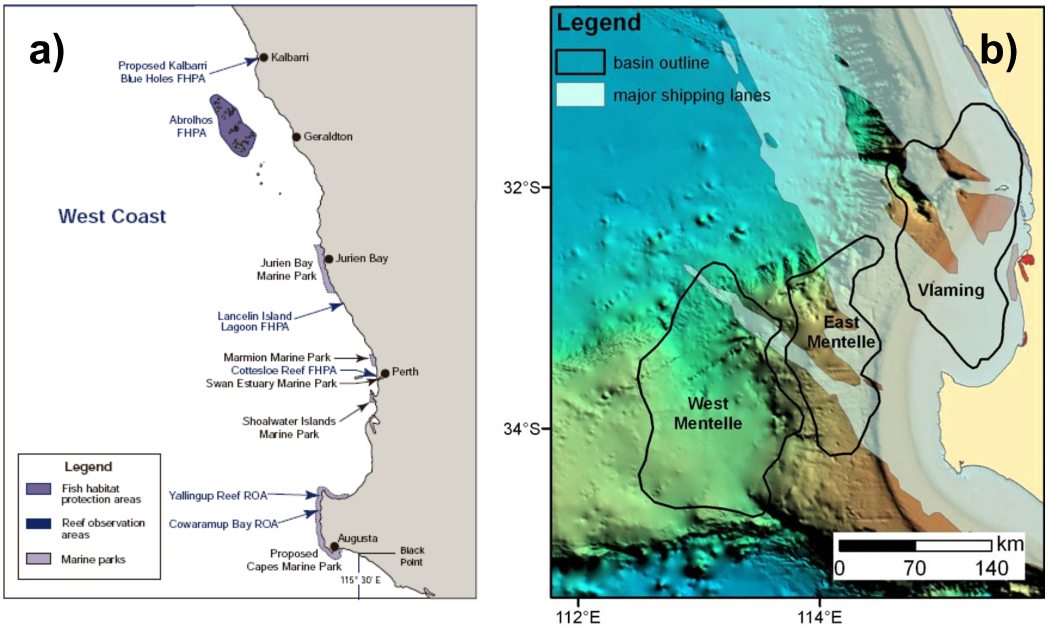


Figure 7.2: *a) Map showing areas of fish and habitat protection within the west coast bioregion (Image from Fletcher and Head, 2006). b) Map of major shipping lanes (beige shaded polygon) within the west coast bioregion. Shipping data supplied by the Australian Maritime Safety Authority derived from data (accuracy ± 6 nautical miles) from commercial ships 2000-2003.*

7.3.2 Shipping Routes

Both the Vlaming Sub-Basin and Mentelle Basin lie within major commercial shipping routes (Figure 7.2b). Vlaming Sub-Basin lies immediately west of Perth and as a consequence most of this Sub-basin (>70% of Vlaming Sub-Basin is within major shipping routes) lies within major commercial shipping routes. Mentelle Basin lies further offshore and is subjected to less commercial shipping traffic (<25% of Mentelle is within major shipping routes), with all major traffic passing over eastern Mentelle but none passing over western Mentelle.

7.3.3 State Fisheries

In 2005/2006 the Western Australian state wild fisheries was valued at $414 million (ABARE, 2007) with the following twelve major state fisheries managed under the jurisdiction of Western Australia (Fletcher and Head, 2006):

- West Coast Rock Lobster Managed Fishery
- Roe's Abalone Managed Fishery
- Abrolhos Islands and Mid West Trawl Managed Fishery
- South West Trawl Managed Fishery (prawns and scallops)
- West Coast Blue Swimmer Crab Fishery
- West Coast Deep Sea Crab (Interim) Managed Fishery
- West Coast Estuarine Fisheries
- Cockburn Sound Finfish Fisheries
- West Coast Beach Bait Managed Fishery
- West Coast Purse Seine Managed Fishery
- West Coast Demersal Scalefish Fishery
- Wetline Fishing

Of these, five fisheries (*Rock Lobster, SW Trawl Fishery, Deep Sea Crab, Purse Seine Fishery and Demersal Scalefish*) are identified here as having some relevance to the Mentelle-Vlaming Region, with many species captured in these fisheries occurring in or around the Mentelle Basin and Vlaming Sub-Basin, as benthic adults or in the water currents as larvae.

7.3.3.1 Western Australian Rock Lobster Fishery (nearshore)
The Western Australian Rock Lobster (*Panulirus cygnus*, the Australian spiny lobster) fishery operates between Cape Leeuwin (34° 24'S) and Shark Bay (24°45'S), and is the most valuable single species fishery (estimated $289 million) taking between 10000 to 14000 tonnes of lobster per year using baited pots (Hall et al. 2000). Three of the five fishing zones (zones: A, B, C) for this fishery lie within the west coast bioregion. *P. cygnus* occur in the nearshore (0-90 m, rarely down to 120) from Northwest Cape (21°48'S) to Hamelin Harbour (34°30'S) and around offshore islands. While benthic adult *P. cygnus* (Figure 7.3a) do not occur within the depth ranges present in the Mentelle Basin, larval phases of this species (Figure 7.3b) are dispersed along the Leewin current and may be present in the epipelagic zones of the water column across the shelf and slope regions of WA (Waite et al., 2007).

7.3.3.2 Southwest Trawl Fishery (Scallops and Prawns)
The southwest trawl fishery is a multispecies fishery which targets prawns and scallops using otter trawls (Kangas, 2006). While a variety of prawn and scallop species occur off the Western Australian coast, the two primary targets for this fishery are the western king prawn (*Penaeus latisulcatus*) and the saucer scallop (*Amusium balloti*). Both species occur in < 100 m water depth on sandy mud sediments. While both species are captured in several fisheries operating along the west coast, most of the southwest trawl fishery is focused on a few small offshore areas for scallops, and in Comet Bay for prawns (Kangas, 2006). In 2005, 14 tonnes of prawns were landed with an estimated value of $176,000, while < 1 tonne of whole weight scallops were landed with an estimated value of $2,000. Like the Australian spiny lobster, the dispersal of larva of *P. latisulcatus* and *A. balloti* are reliant on the strength and timing of Leewin current.

7.3.3.3 West Coast Deep Sea Crab Fishery
The West Coast Deep Sea Crab fishery targets three deep-sea crab species: *Pseudocarcinus gigas* (giant king crab - Figure 7.3c), *Chaceon bicolor* (crystal snow crab) and *Hypothalassia acerba* (champagne spiny crab) that occur in deep soft mud habitats off the coast of Western Australia. The fishery operates in water depths of 150 to 1,200 m between Cape Leeuwin and the Northern Territory border. Crabs are captured using a series of baited pots (50-100 pots) that are set along a long-line (Melville-Smith, 2006). All three species occur over the depth present in Mentelle-Vlaming region. *H. acerba* occur abundantly in depths between 145-310 m (Smith et al., 2004), while *C. bicolor* is found over a broader depth range of 275 m down to at least 1,600 m (Wadley 1992). In 2005, 207 tonnes of crabs were landed with an estimated value of $2.7 million. Deep-water crabs are long-lived and slow growing, which makes them extremely vulnerable to overfishing (Smith et al., 2004).

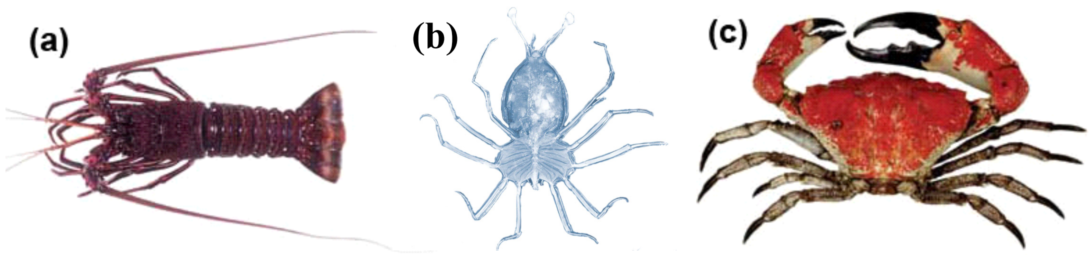


Figure 7.3: *Commercially-important crustaceans found in the west coast bioregion: a) Australian spiny lobster (Panulirus Cygnus) occurs inshore, b) Panulirus Cygnus larvae occur offshore, c) Giant crab (Pseudocarcinus gigas) found offshore in deeper waters. Images a) and c) modified from* www.fish.gov.au, *and b) modified from Southern Surveyor Survey photograph (SS05/06, University of Western Australia).*

7.3.3.4 West Coast Purse Seine Fishery (Pilchards and Sardines)

The purse seine fishery targets a combination of small pelagic fishes from pelagic waters off the west coast of Western Australia between latitudes 31° to 33° S. Target species include pilchards (*Sardinops sagax*) and the tropical sardine, *Sardinella lemuru,* along with a range of other minor species (e.g. Perth herring, *Nematalosa vlaminghi*, yellowtail scad, *Trachurus novaezelandiae*, Australian anchovy, *Engraulis australis*, and maray, *Etrumeus teres*). In 2005 379 tonnes of small pelagics were landed with an estimated value of $358,000. Importantly, pilchards and other small pelagic fish, which eat zooplankton, are themselves consumed by a variety of larger fish, sharks, and cetaceans and as such are a fundamental link in the food web of the west coast pelagic ecosystem. While the west coast purse seine fishery is healthy and fished well below stock levels overfishing of this tropic level could have severe consequences on higher level predators and the functioning of the pelagic ecosystem (Leary and Gaughan, 2006).

7.3.3.5 West Coast Demersal Scale Fishery (Dhufish, Pink Snapper, Emporers, Grouper, Cod, Coral trout, Shark)

This fishery uses baited handlines and longlines to target a diverse mixture of demersal (benthic) fish species from the coast to deep slope habitats between latitudes 26-33^o S. The two primary target species one dhufish (*Glaucosoma hebraicum*) which occurs nearshore (< 50 m water depth) and pink snapper (*Pagrus auratus*) which occurs to 200 m. These species are used as the main indicator species for the fishery, but emperors (*Lethrinus* species), baldchin groper (*Choerodon rubescens*), grey-banded cod (*Epinephelus octofasciatus*) and coral trout (*Plectropomus leopardus*) are also taken along with a range of shark species, including Wobbegongs (Orectolobidae), gummy shark (*Mustelus antarcticus*), whiskery shark (*Furgaleus macki*), and whalers (Copper whaler (*Carcharhinus brachyurus*) and Dusky whaler (*Carcharhinus obscurus*)) (St John and King, 2006) (Figure 7.4). In 2005, 1,220 tonnes of demersal scale fish were landed in Western Australia with an estimated value of $7.8 million.

Many deep-water fishes captured in this fishery occur in and around the Mentelle Basin and Vlaming Sub-Basin , including the target species *P. auratus* (Pink

Snapper), as well as *Centroberyx affinis* (Redfish), *Hyperoglyphe antarctica* (Deepsea trevalla), and two whaler sharks (*Carcharhinus brachyurus*, the Copper whaler, and *Carcharhinus obscurus*, the Dusky whaler) (Table 10.1 and 10.2).

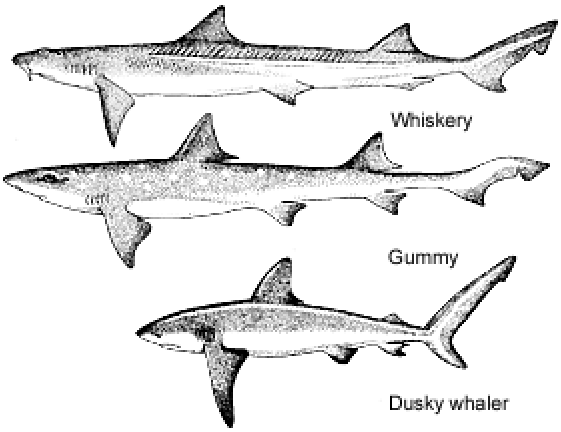


Figure 7.4: *Example of the types of sharks captured off Western Australia: whiskery shark (Furgaleus macki) gummy shark (Mustelus antarcticus), and dusky whaler sharks (Carcharhinus obscurus). Image from: http://www.fish.wa.gov.au/docs/cf/Sharks/index.php?0206*

7.3.4 Commonwealth Fisheries

A variety of commonwealth fisheries targeting finfish, crustacean, and shellfish are prevalent in Western Australian waters, with five specifically occurring within the west coast bioregion: the Southern Bluefin Tuna Fishery, Western skip jack fishery, Western Tuna & Billfish, Small Pelagic Fishery, and the Western Trawl Fishery. These fisheries target fishes from a range of different water depths and marine environments (Figure 7.5). The Southern Bluefin Tuna Fishery, Western skip jack fishery, Western Tuna & Billfish, and the Small Pelagic Fishery target migratory and local epipelagic and mesopelagic species, while the Western Trawl Fishery targets a broad range of demersal, bathydemersal, and bathypelagic species.

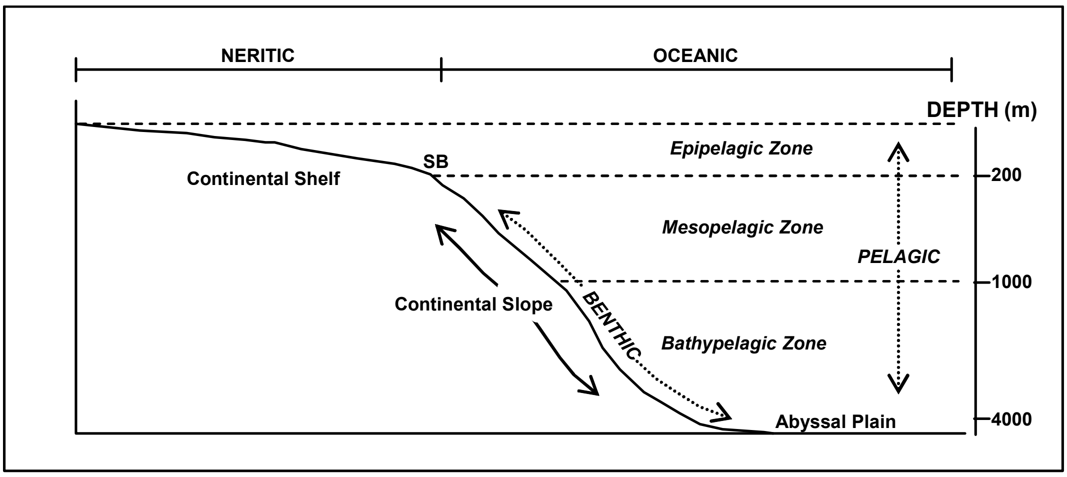


Figure 7.5: *A cross-sectional view of the continental shelf, slope, and abyssal plain environments and the biotic zones typical to the Australian Fishing Zone. SB indicates the location of the shelf break. (Image modified from http://www.afma.gov.au/information/publications/fishery/baps/docs/sharksentbkgd.htm)*

7.3.4.1 Southern Bluefin Tuna Fishery (Oceanic)

Southern bluefin tuna (*Thunnus maccoyii*) (Figure 7.6a) is an extremely valuable single-species fishery. *T. maccoyii* is a highly migratory epipelagic species with a broad Southern Ocean distribution that includes the west coast of Australia. The majority of fish landed in this fishery are captured in oceanic purse seines off the Great Australian Bight and the south eastern coast of Australia, although this species is captured within the west coast bioregion. After capture, live tuna are transported to Port Lincoln in south-eastern Australia and grown in fish-pens to increase their value on the Japanese market - providing an estimated value of $150 million per annum.

7.3.4.2 Western Skipjack Fishery (Oceanic)

Skipjack tuna (*Katsuwonus pelamis*) (Figure 7.6b) is also a highly valuable epipelagic fishery, with skipjack comprising over 97% of all fish landed. Oceanic purse seines are used to catch over 95% of total landings for this fishery, although mid-water long-lines and hand-lines are also used. Other minor species captured in this fishery include bigeye and yellowfin tuna, frigate mackerel, sharks, mahi mahi, rays and marlins, but these make up less than 3% of the total catch. Like southern bluefin tuna, skipjack are captured off the south-eastern to western coasts of Australia, and are then transported back to Port Lincoln.

7.3.4.3 Western Tuna and Billfish Fishery (Oceanic)

The Western Tuna and Billfish Fishery (WTBF) capture a variety of tuna and billfish (Figure 7.6) using sub-surface longlines and oceanic purse seines. The fishery extends over a broad geographic range spanning westward from the Cape York Peninsula to the South Australian/Victorian border. Species targeted by this fishery include the yellowfin tuna (*Thunnus albacares*) bigeye tuna (*T. obesus*) albacore tuna (*T. alalunga*), and the broadbill swordfish (*Xiphias gladius*) all of which occur in waters in and around the Mentelle Basin and Vlaming Sub-Basin (Figure 7.6 c-f). Over the last seven years total national landings have decreased considerably from 4253 tonnes in 2001 having an estimated value of $33.7 million to 926 tonnes in 2006 with an estimated value of $3.2 million.

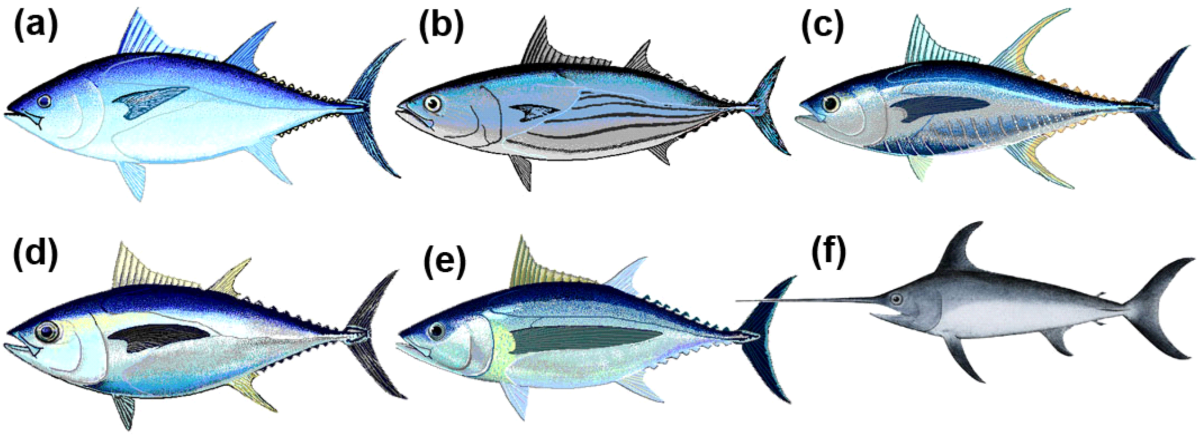


Figure 7.6: *Targeted species for the Southern Bluefin, Skipjack, and Western Tuna and Billfish fisheries found in or around the Mentelle and Vlaming Sub-Basins. (a) Southern bluefin tuna (Thunnus maccoyii), (b) Skipjack tuna (Katsuwonus pelamis), (c) Yellowfin tuna (T. albacares), (d) Bigeye tuna (T. obesus), (e) Albacore tuna (T. alalunga), and (f) Swordfish (Xiphias gladius). Images modified from* http://www.fishbase.org.

7.3.4.4 Small Pelagic Fishery

The Small Pelagic Fishery (SPF) is a temperate fishery that extends beyond 3 nm south of latitude 28° S in Queensland around to 31° in Western Australia. The fishery is separated into four fishing zones, with Western Australia and South Australia falling within zone B. A variety of small epipelagic fishes are targeted using oceanic purse seines and mid-water trawls. Target species include jack mackerel (*Trachurus declivis* and *T. symmetricus*), blue mackerel (*Scomber australasicus*), yellowtail scad (*T. novaezelandiae*), and redbait (*Emmelichthys nitidus*) (Figure 7.7). Although this is a relatively small fishery, small pelagic fishes are a critical component of mid-trophic food webs, and as such are likely to be fundamental in the functioning of the broader pelagic ecosystem.

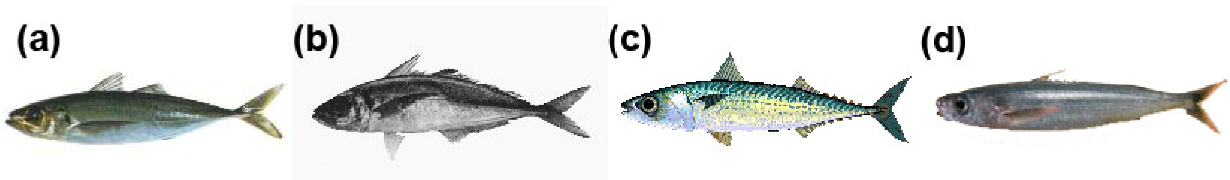


Figure 7.7: *Targeted species for the small pelagic fishery found in or around the Vlaming Sub-Basin / Mentelle Basin.*

(a) jack mackerel (Trachurus declivis), (b) yellowtail scad (T. novaezelandiae, (c) blue mackerel (Scomber australasicus), (d) redbait (Emmelichthys nitidus). Images modified from http://www.fishbase.org.

7.3.4.5 Western Trawl Fishery (WTF)

The Western Trawl Fishery (WTF) is composed of two fisheries, the Western Deepwater Trawl Fishery (WDWTF) and the North West Slope Trawl Fishery (NWSTF). Both are multispecies fisheries that use demersal trawl gear, with the WDWTF targeting deep-water bugs (slipper lobsters, Family: Scyllaridae) and a broad mixture of finfish, while the NWSTF targets scampi and deepwater prawns (Moore et al., 2007). Sponges, jellyfishes, squid, sharks and rays, and a range of non-target crustacea are also captured by these fisheries as bycatch. While the Western Deepwater Trawl Fishery works directly within the west coast bioregion, the North West Slope Trawl Fishery works further north in the Northwest Bioregion. However, most of the species captured in these two fisheries are present in the Mentelle-Vlaming region. Demersal trawl gear used in this fishery can have a negative impact on the seafloor by removing structurally complex biota, such as the removal of the once common Hexactinellid sponges by western trawl gear (Phillips and Wallner, 1992).

o *The Western Deepwater Trawl Fishery (WDWTF)* operates from ~17-36^{o} S between the 200 m isobath out to the edge of the Australian Fishing Zone (generally within the 200-1500 m depth range) and targets a mixture of deep-water demersal fishes and bugs using demersal trawl gear – with no one species captured in large quantities making the catches opportunistic (Moore et al., 2007). A diverse array of finfish species are captured and range from northwest ruby fish (*Etelis carbunculus*), tang snapper (*Lipocheilus carnolabrum*), and deepwater flathead (*Neoplatycephalus conatus*) on the shelf edge, to deeper species such as gemfish (*Rexea solandri*), mirror dory (*Zenopsis nebulosus*), oarfish (*Pentaceros* spp), orange roughy (*Hoplostethus atlanticus*) and oreo species (Oreosomatidae) on the slope (Evans, 1992) (Figure 7.8). Deep-sea bugs captured in this fishery generally comprise *Ibacus altricrenatus* and *I. ciliatus pubescens*. In 2004, 109.5 tonnes from this fishery were landed for the domestic market with an estimated value of $979,600.

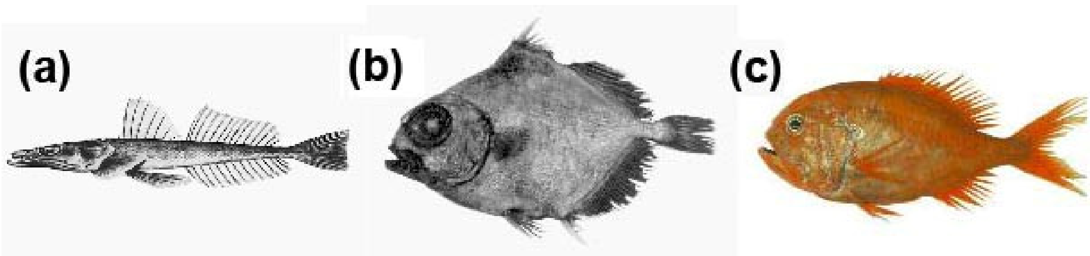


Figure 7.8: *Targeted species for the Western deepwater trawl fishery: (a) deepwater flathead (Neoplatycephalus conatus), (b) oreo species (Oreosomatidae), and (c) orange roughy (Hoplostethus atlanticus)*

o *The North West Slope Trawl Fishery (NWSTF)* operates from 114°E to about 125°E off the Western Australian coast between the 200 m isobath out to the edge of the Australian Fishing Zone (generally within the 200-1500 m depth range) and targets a mixture of deep-water scampi and prawns using demersal crustacean trawls. The primary targets of this fishery are four scampi species (clawed lobsters: *Metanephrops velutinus*, *M. australiensis*, *M. boschmai*, and *M. sibogae*) and six deep-water prawn species (4 penaeid species (*true prawns)*: *Haliporoides sibogae, Aristaeomorpha foliacea*, *Aristeus virilis*, *Plesiopenaeus edwardsianus*), and 2 carid species (*true shrimp) Heterocarpus woodmasoni*, *H. sibogae* (Wallner and Phillips, 1995). Species of scampi and deep-sea prawns vary with depth and are closely associated with soft-sediments in which they bury during the day (Ward and Rainer, 1988). Crustacean species captured in NWSTF prey mostly on other crustacea but also feed on a variety of benthic (e.g. polychaete worms, echinoderms, sea-snails, and small bivalves) and pelagic (e.g. squid, jellyfish, and fish) species, and in turn are preyed upon by a variety of cephalopods and fishes (Rainer, 1992b).

7.3.5 Animal Migration Pathways

A range of marine creatures including whales, turtles, pelagic fishes, and crustacea are known to migrate through the west coast bioregion (Table 7.1). Humpbacks, right whales, and blue whales migrate through the region on their way to and from northern breeding grounds. The seasonal presence of these whales, following their migration from cold Antarctic waters to breed in the warm temperate to sub-tropical waters of Western Australia, now supports a prosperous whale watching and tourism industry in the region. Turtles - the Green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), and loggerhead (*Caretta caretta*) - occur in offshore waters within the west coast bioregion during their migration to and from their nesting grounds in the tropical north. The leatherback (*Dermochelys coriacea*) and olive ridley (*Lepidochelys olivacea*) turtles are also present in western Australia but do not nest there. These species are all protected under *the EPBC Act.*

Table 7.1: Animal migration activities within the west coast bioregion.

Marine Activity	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Blue Whale aggregation Perth Canyon	■	■	■	■								■
Humpback whale north migration						■	■	■				
Humpback whale south migration									■	■		
Commercial whale watching									■	■	■	
Turtle migration and nesting	■	■	■	■					■	■	■	■

7.4 PREVIOUS WORK AND DATA SOURCES

7.4.1 Overview of existing data

While nearshore communities in Western Australia have received considerable attention, prior to the 1990's very little was known about the offshore communities of Western Australia. Several exploratory fishery surveys were conducted in the 1980's to examine the potential for offshore finfish and deep-sea crustacean (scampi and prawns) fisheries (Jernakoff, 1988), but little was known about the broader composition of these deep offshore communities. Since then, three fishery-independent research surveys (SS01/1991, SS07/2005, and SS10/2005) have specifically examined the benthic communities in these deep offshore environments across broad latitudinal (20^{o} and 35^{o} S) and depth (100 to 1500 m) gradients, while one seafloor mapping survey (SS08/2005) examined the geomorphology of specific locations within the area (Table 7.2). The data, reports, and publications arising from these four surveys provide a range of preliminary information on deep-sea shelf and slope habitats and communities, and where relevant are discussed in the sections following. Overall the biological information from the Vlaming Sub Basin and Mentelle Basin are limited to a few sampling stations from a limited number of depths and locations.

To provide a regional overview of species occurrences, species lists for Vlaming Sub Basin and Mentelle Basin were obtained from two databases: the Ocean Biogeographic Information System (OBIS) and the Museum of Victoria. OBIS is a Census of Marine Life website (http://www.iobis.org.) that collates known species occurrence at 1^{o}, 5^{o}, and 10^{o} map grids. To create a species list for the area in and around Mentelle Basin and Vlaming Sub-Basin a 5^{o} radius (latitudes 30-35^{o} and longitude 110-115^{o}) was searched. The full list of species attained is compiled in Table 10.1 for pelagic species, and 10.2 for benthic species.

This table does not represent a comprehensive account of the fauna present in both the Vlaming Sub-Basin and Mentelle Basin, because it is heavily biased towards commercially-caught species (e.g. fishes) and current taxonomic priorities (e.g. crustacea have been processed to species by the Museum of Victoria but Molluscs have not yet been sorted and are therefore not included in the Museum database). The combinations of these data are used here to provide an overview of the known bio-physical environment for the west coast bioregion with specific relevance to the Mentelle Basin and Vlaming Sub-Basin. Knowledge gaps are also highlighted and discussed.

Table 7.2: Surveys undertaken offshore of Western Australia examining benthic habitats and biota. GA = Geosciences Australia, MoV = Museum of Victoria, CSIRO = Commonwealth Scientific and Industrial Research Organisation

Survey ID/year	Agency	Latitude range	Depths(m)	Gear types (number of samples)
SS01/91	CSIRO	20-35°S	200-1500	Bottom trawl (95), commercial bottom trawl (56)
SS07/05	CSIRO		100-1000	EM300 multibeam, towed video camera (64), grab (107), Sherman benthic sled (2), boxcore (2)
SS08/05	GA	31-33°S		multibeam, gravity cores (24), benthic sled (2), rock dredge (12), grab (3), boxcore (1), camera (121 stills from 14 stations)
SS10/05	CSIRO & MoV	20-35°S	100-1000	multibeam, benthic sleds (Sherman sled, beam trawl)

7.4.1.1 FRV Southern Surveyor Cruise SS01/97

In January 1991, CSIRO fishery researchers undertook a deep water trawl survey (SS01/91) on board the FRV Southern Surveyor to examine the composition of deep water fishes off Western Australia between latitudes 20^{o} and 35^{o} S at depths of 200-1500 m (Williams et al., 1996; Williams et al., 2001). Ninety five stations were sampled within 6 depth zones at 200 m increments, with additional 56 stations targeted using commercial trawls.

7.4.1.2 RV Southern Surveyor Cruise SS07/05 and SS10/05

In July and November of 2005, the CSIRO Wealth from Oceans flagship Voyage of Discovery undertook a two-part survey (SS07/05 and SS10/05) on the Southern Surveyor to i) map deep (˜200-1000 m) offshore shelf and slope environments between latitudes 31^{o} and 33^{o} S off Australia's south west, and ii) examine the composition of the deep water benthic invertebrates (epifauna and infauna) that occur there.

In July 2005, part 1 of the survey (SS07/05) used a deep water multibeam (EM300) to acoustically map the seafloor within deep continental shelf and slope areas off Western Australia. 64 towed video transects were used to characterise the benthos in these areas, while 107 Smith MacIntyre grabs, 2 Sherman benthic sleds, and 2 boxcores were employed to sample the epifauna and infauna. In November 2005, part 2 (SS10/05) of the survey on the RV Southern Surveyor collected benthic invertebrate epifauna and infauna from 132 Sherman benthic sleds at depths from 100 m, 200 m, 400 m, 700 m and 1000 m.

(http://www.marine.csiro.au/nationalfacility/voyagedocs/2005/summary_ss07-2005.pdf)
(http://www.marine.csiro.au/nationalfacility/voyagedocs/2005/Summary_SS10-2005.pdf)

7.4.1.3 FRV Southern Surveyor Cruise SS08/05

In September 2005 (SS08/05) Geosciences Australia characterized benthic habitats and sedimentary processes in the east Mentelle Basin using the RV Southern Surveyor. The Southern Surveyors deep water multibeam (EM300) was used to acoustically map the seafloor within the east Mentelle Basin, while 24 gravity cores, 12 rock dredges, 12 grab samples, 2 benthic sleds, 1 boxcore, and 121 still photographs were used to characterise the geopmorphology of the area (*GA unpublished report*).

(http://www.marine.csiro.au/nationalfacility/voyagedocs/2005/Summary_SS08-2005.pdf)

7.4.2 The Pelagic Ecosystem of the West Coast Bioregion

The oceanic waters of the West Coast are characterized by temperate and oligotrophic conditions with limited amounts of nutrient rich upwelling or terrigenous inputs that, in turn, contribute to the overall low productivity and high water clarity in this region. While this environment supports a plethora of pelagic and bathypelagic species, including cephalopods, sharks, and fishes, the abundances of species are generally low (Appendix 10.1; Jernakoff, 1988), with only small (e.g. pilchards) and large (e.g. tunas and billfishes) pelagic fishes being deemed commercially viable or sustainable (Jernakoff, 1988; Rainer 1992a). However, this offshore environment supports a complex multi-trophic assemblage that includes a variety of migratory, transient, and local populations that interact within a complex food web. Pelagic cephalopods and fishes are important components of the food web being prey to large predators (e.g. large pelagic fishes, sharks, and whales) and as predators of other species. For example the flying squid, *Ornithoteuthis volatilis*, commonly caught in the western trawl fishery, preys upon a variety of pelagic squids and is also prey for a broad range of apex predators including swordfish and yellowfin tuna, lancetfish, and dogsharks (Rainer, 1992a). Similarly, scombrids such as tuna and mackerel that commonly occur off Western Australia prey on a diversity of small fishes, crustaceans, and cephalopods, and may exert a significant predation pressure on epipelagic and mesopelagic prey communities (e.g. Potier et al., 2004). The presence and feeding activities of bathypelagic and bathydemersal fishes, cephalopods and sharks might also act as vital energetic and ecological links between these oceanic and bathydemersal ecosystems.

Complex seafloor bathymetry can also have important consequences on the overlying pelagic environment. Localised eddies, for example, that occur within the Perth Canyon induce local and variable upwellings (Rennie et al., 2006). These upwellings are associated with high chlorophyll levels within the canyon that support dense swarms of krill (*Euphausia recurva*). Satellite tracking and visual monitoring of cetaceans in the region have identified that the Perth Canyon is an important feeding ground for humbacks (*Megaptera novaeangliae*), pygmy blue whales (*Balaenoptera musculus brevicauda*), blue whales (*Balaenoptera musculus*, Figure 7.9).

Cetaceans: Thirty five species of cetaceans (whales and dolphins) have been recorded from coastal and oceanic environments off Western Australia, and include humpbacks (*M. novaeangliae*) and southern right whales (*E. australis*), along with the rarer blue whales (*B. musculus*). Common and bottlenose dolphins (*Tursiops* sp.), sperm whales (*Physeter macrocephalus*), beaked whales (*Mesoplodon* sp.), and Risso's dolphins *(Grampus griseus*) have also been observed in this region. Many cetacean species occurring within the west coast bioregion are listed as either endangered (e.g. blue whale) or vulnerable (e.g. Humpbacks) under the EPBC Act.

Marine Turtles: Five species of marine turtles (Green, hawksbill, loggerhead, leatherback and olive ridley) commonly occur in the waters of Western Australia. All five species are listed as vulnerable under the EPBC Act and are likely to occur in and around Mentelle Basin and Vlaming Sub-Basin (Table 7.1).

Sharks and Rays**:** A broad variety of pelagic sharks occur off the west coast of Australia, and include the great white, grey nurse (*Carcharias taurus*), whalers, and makos. Many shark species are captured in state and commonwealth fisheries both as bycatch and as targets for their fins. Sharks however are highly vulnerable to overfishing due to their life history characteristics (e.g. low fecundity, age to maturity). As a consequence, many shark species are now listed on the IUCN Red List of Threatened species 2000 (e.g. Grey nurse shark) and EPBC Act 1999 (e.g. several dogfish species (*Centrophorus harrisoni, C. uyato*, and *C. moluccensis*). The area in and around the Mentelle Basin and Vlaming Sub-Basin are specifically characterized by the presence of numerous epipelagic (e.g. whalers) and bathypelagic (e.g. deep-sea dogfish) species (Appendix 10.1).

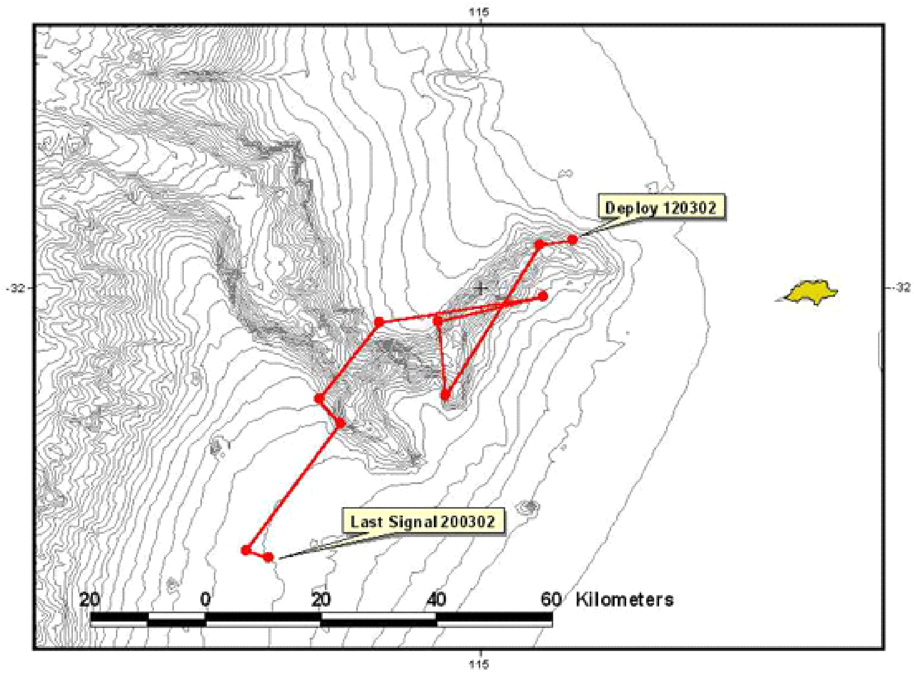


Figure 7.9: *Bathymetric map of the Perth Canyon with the satellite track of a single tagged blue whale within the Perth Canyon, 12-20 Mar 2002 (from: http://www.cmst.curtin.edu.au/research/wa_bluewhales/wabluewhales/frames/sattag.htm).*

Pelagic Fishes: A wealth of small (e.g. jack mackerel) and large epipelagic fishes (e.g. Southern bluefin tuna, Wahoo, and Black marlin) occur offshore of Western Australia, while deeper pelagics or bathypelagic species (e.g. hatchetfish and lanternfish) are also common (Appendix 10.1). Several fish and shark species are now listed as endangered due to over fishing and are protected under local, commonwealth or international legislation. For example, blue and black marlin are both protected under Commonwealth legislation, while the striped marlin is protected under Western Australian state legislation.

7.4.3 The Benthic Ecosystem within the West Coast Bioregion

The benthic marine profile off Western Australia comprises the nearshore (˜0-20 m), continental shelf (˜20-170 m), upper and lower continental slope (˜170 - 3,000 m) and abyssal plain habitats (>4,000 m). In the nearshore, intertidal and subtidal platform reefs are narrow alongshore (0-20 m) and support highly diverse coral reef assemblages. While considerable research exists on the nearshore, up until 2005 little was known about the offshore habitats comprising the continental shelf and slope regions of Western Australia. In 2005, geomorphological and biological samples were collected from the shelf and slope regions of Western Australia. Most samples characterised sandy mud sediments, with some indication of increasing mud content with depth (Chapter 5). These soft sediment habitats were characterized by flat relief and low to moderate levels of bioturbation – caused by a diverse range of infaunal (e.g. burrowing polychaete worms) and burrowing epifaunal (e.g. burrowing crustacean and fishes) activities. In contrast to an abundant and highly diverse infauna, the shelf and slopes in these areas were inhabited by very sparse epibenthic assemblages that included low occurrences of solitary anemones, seapens, urchins, seastars, crustaceans, and demersal fishes (CSIRO unpublished report).

In contrast to soft-sediment habitats, areas of seafloor comprising hard substrata were infrequent and patchy (CSIRO unpublished report). Outcrops of hard reef were found as low and high-relief features but were restricted to areas on the northern flanks of Perth Canyon and at most depths at Two Rocks - a station immediately north of Perth Canyon. These exposed reefs support moderate to dense epibenthic assemblages characterised by habitat formers such as sponges, hydroids, gorgonians, and soft corals (CSIRO unpublished report), as well as a range of motile species, such as deep-water crabs, squat lobsters, and fish.

A variety of environmental variables are likely to be important in structuring offshore benthic assemblages in this region. Several studies conducted off the west coast have identified depth and bottom type to be major factors in the distribution of infauna (Rainer 1991), crustacea (Ward and Rainer, 1988) and fishes (Williams, et al., 2001). Sediment characteristics of the seafloor (e.g. grain size) are also likely to be critical to infaunal species that burrow into and along the surface of soft-sediments (e.g. polychaete worms; Rainer 1991; Table 10.2) and deep-sea crustacean (e.g. scampi and prawns) that burrow into soft-sediments (e.g. Ward and Rainer, 1988; Wallner and Phillips, 1995). Studies conducted in these benthic offshore environments have all recorded extremely high species diversities for a range of functional groups, but low biomass and abundances, suggesting that these patterns are linked to the low primary productivity of the broader oligotrophic environment.

Demersal and Bathydemersal Fishes and Sharks: In 1991 the FRV Southern Surveyor (survey#: SS01/91) sampled deep-water fishes from continental shelf and slope habitats over a broad region of WA (20 to 35^{o} S, and 200-1300 m water depth). The finding of this study identified a highly diverse fish fauna (388 demersal fish species from 108 families), but very low fish densities, and low overall abundances of all species (Williams, 1992; Williams et al., 1996; Williams et al., 2001). This high diversity was attributable to low primary productivity and the overlap between tropical and temperate species. Six of the seven assemblages described in Williams *et al.*, occurred within the west coast bioregion (Table 7.3) and varied by depth and latitude, with the highest densities occurring within the region of the shelf break. Five assemblages varied by depth, with the 700-900 m depth zone split into two latitudinally different assemblages (Table 7.3). A large number of fish and shark species (Table 7.3, Table 10.2) are captured in the Western Deepwater Trawl Fishery, however many of these demersal and bathydemersal species can be long-lived, slow-growing, and late to mature, making them highly vulnerable to overfishing. A variety of deep-water demersal (e.g. catsharks), bathydemersal (e.g. lantern sharks), and benthopelagic sharks (e.g. bamboo sharks) are recorded from the region (Table 10.2). Many of these elasmobranchs are also captured in the Western Deepwater Trawl Fishery.

Cephalopods: Several deep-water demersal cephalopods have been recorded from Mentelle Basin and Vlaming Sub-Basin, and include several species of benthic squids *Sepia* and *Rossia* species (Table 10.2). *Rossia* are a genus of small cuttlefish (sepiolids) generally found in depths greater than 50 m, while most *Sepia* species (Bobtail squids) generally inhabit coastal waters although some species occur on the continental slope to a depth of 500 m. These species often bury in soft sediments. Within the Mentelle and Vlaming region three deep-water *Sepia* species have been recorded (Table 10.2). Deep-sea octopuses also occur in the region (Table 10.2): *Benthoctopus* sp. (deep-water genus lacking an ink sac) was recorded from depths of 800 m, but may occur to depths of 3,000 m (Norman, 2000), while *Eledone palari* (Horned octopus) are associated with the benthos on the continental shelf and slope, and are active predators that feed on a range of benthic crustacean (lobsters, crabs, and shrimp) (Norman, 2000).

Crustacea: Deep-water mobile epibenthic crustacea such as crabs, prawns, scrimp, bugs, and scampi (Table 10.2) are a key component of shelf and slope communities in Western Australia. Motile epibenthic crustacean are thought to be important prey for a variety of fishery targeted species (Ward and Rainer, 1988). Scampi and deep-water prawns – initially targeted by the Western Deepwater Trawl Fishery pre-1990 - are now captured as valuable bycatch, while further north these species remain the target of the North West Slope Trawl Fishery. Crustacean assemblages off Port Headland on the northwest slope (NWS) were characterized by exceptional high species diversity (Ward and Rainer, 1988), with species associated with depth, sediment type, and bottom type. Scampi, for example, are associated with soft sediments where they build extensive burrows and hence are strongly correlated with sediment type and grain size (Wallner & Phillips, 1995). Many species captured in Ward and Rainer’s study are also found on shelf and slope habitats further south in and around Mentelle basin and Vlaming Sub-Basin mostly at depths < 400 m (Williams, 1992), indicating that depth and habitat characteristics are also likely to be important in understanding species distributions within the west coast bioregion. In the northwest, several crustacean species (e.g. *Portunus pseudoargentatus*) were associated with large sedentary fauna such as sponges (Ward and Rainer, 1988), while these species are also likely to occur further south no comparative study has been conducted in the west coast bioregion to identify this.

Infaunal assemblages: Shelf and slope sediments on the west coast are characterised by a variety of bioturbation activity (Figure 7.10). A detailed infaunal survey undertaken on the northwest shelf using a Smith McIntyre grab (Rainer, 1991) identified that infaunal assemblages were characterized by high diversity, dominated by polychaete worms with small body sizes. In Rainer’s study, infaunal abundance and species richness decreased with depth, but this pattern was also confounded by decreasing habitat complexity with depth. Twenty three families of polychaete worms have been recorded from Vlaming Sub-Basin and Mentelle Basin, and include a range of tubeworms, burrowers, reef dwellers, and coral-borers from a variety of functional groups: deposit feeding to predaceous carnivores (Table 10.2). Small fishes and epibenthic crustacea that prey on these infaunal worms are also likely to be important drivers in maintaining high infaunal diversity (Rainer, 1991).

Table 7.3. Deep-water fish assemblages off Western Australia as identified and described in Williams et al. (2001). Depth and latitude were the two most important variables describing these assemblages (Williams et al., 2001). Here, we include depths and latitudes present within the Mentelle and Vlaming Sub-Basins - modified from Figure 5d in Williams et al., 2001.

Benthic Zone	Depth (m)	Fish Species (common names)	Environment
Shelf-break (south)	200-400	*Pristiophorus cirratus* (Longnose sawshark †)	demersal
		Pterygotrigla polyommata (Latchet †)	demersal
		Neoplatycephalus conatus (deepwater flathead *)	demersal
			demersal
		Kathetostoma nigrofasciatum (deepwater stargazer)	bathydemersal
			bathydemersal
		Squatina tergocellata (Ornate Angel Shark †)	
		Urolophus expansus (Wide stingaree †)	
upper-slope (shallow)	300-500	*Caelorinchus mirus* (Gargoyle fish †);	demersal
		Apogonops anomolus (3-spined cardinalfish)	demersal
		Squalus mitsukurii (Shortspine spurdog †)	bathydemersal
		Chlorophthalmus sp C (Greeneye)	bathydemersal
		Hoplostethus latus (Giant sawbelly †)	bathydemersal
		Notopogon xenosoma (Longspine bellowfish)	bathydemersal
		Helicolenus barathri (Bigeye sea perch)	bathydemersal
		Euclichthys polynemus (Eucla cod †)	bathypelagic
upper-slope (deep)	500-700	*Caelorinchus charius* (Grenadier †)	*bathydemersal*
		Malacocephalus laevis (Softhead grenadier †)	*bathydemersal*
		Ventrifossa sazonovi (Grenadier †)	*bathydemersal*
		Bathyclupea sp A (Deep-sea scalyfins)	*bathypelagic*
		Neoscopelus sp A. (Lanternfish)	*bathypelagic*
mid-slope (shallow-north)	700-950	*Rouleina guentheri* (Slickhead/smelt)	*bathypelagic*
		Neoscopelus macrolepidotus (Large-scaled lanternfish)	*bathypelagic*
		Mataeocephalus acipenserinus (Sturgeon grenadier)	*bathypelagic*
(shallow-south)	700-950	*Deania calcae* (Birdbeak dogfish †)	*bathydemersal*
		Etmopterus lucifer (Blackbelly lanternshark)	*bathydemersal*
		Trachyscorpia capensis (Cape rockfish)	*bathydemersal*
		Mora moro (common morid cod †)	*bathypelagic*
		Neocyttus rhomboidalis (Spiky oreo *)	*bathypelagic*
mid-slope (deep)	900-1300	*Nezumia wularnia* (*Grenadier* †)	*bathydemersal*
		Trachonurus yiwardaus (*Grenadier* †)	*bathydemersal*
		Bathypterois ventralis (Tripod fish)	*bathydemersal*
		Synaphobranchus brevidorsalis (Shortdorsal cutthroat eel)	*bathydemersal*
		Scombrolabrax heterolepis (Longfin escolar)	*benthopelagic*
		Narcetes lloydii (Slickhead)	*bathypelagic*
		Bathygadus spongiceps (Grenadier †)	*bathypelagic*
		Sphagemacrurus pumiliceps (*Grenadier* †)	*bathypelagic*

** = commercially targeted or important species*
† = minor commercial importance (bycatch, or low numbers)

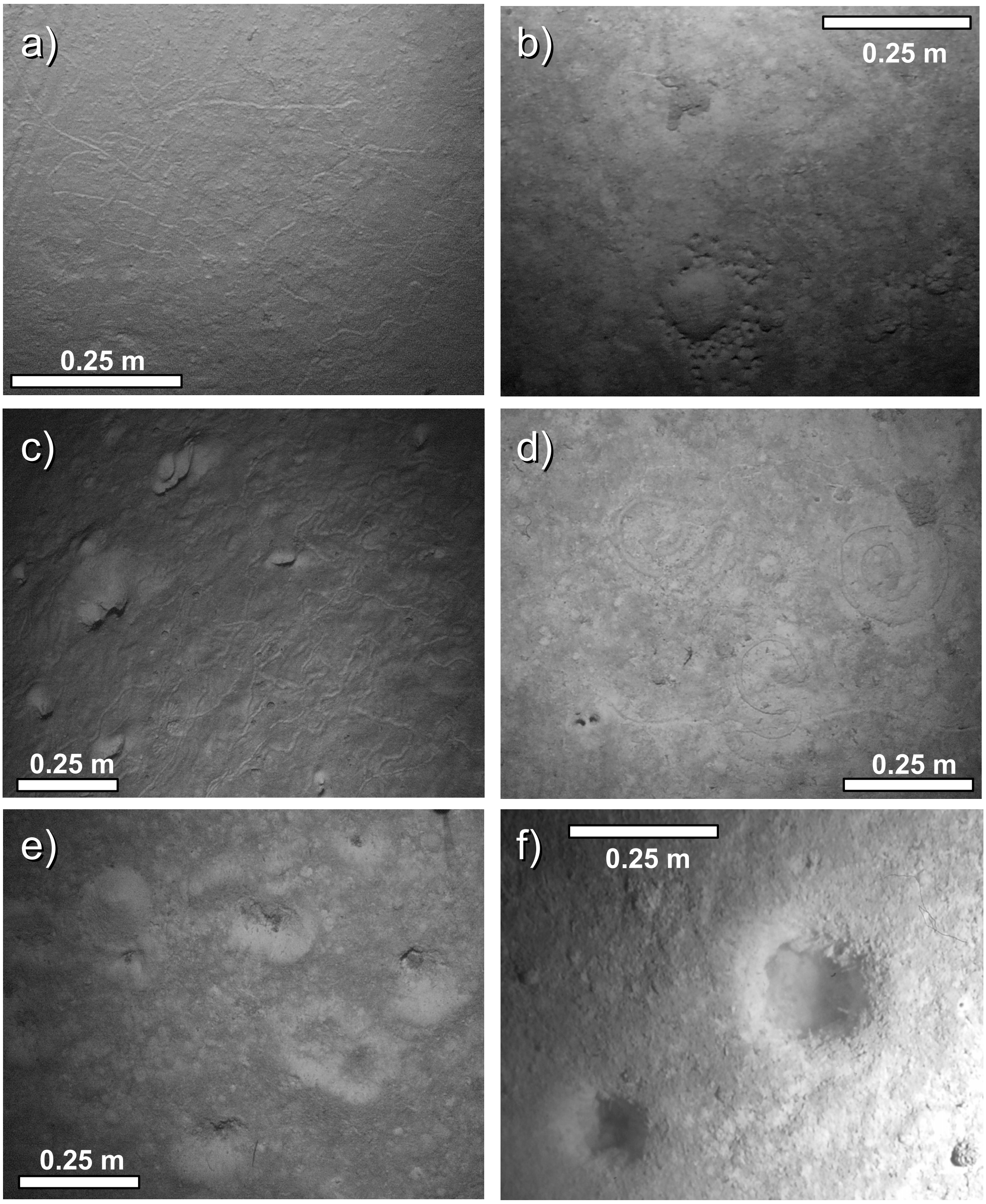


Figure 7.10. *Still photographs from Vlaming Sub-Basin and Mentelle Basin habitats collected during Geosciences Australia's SS08/2005 survey depicting a broad variety of bioturbator activities. a) threadlike worm tracks from Perth Canyon 2035 m, b) starburst pattern from 2764 m in Busselton Canyon, unknown cause/creature, c) variety of crators, pits, and tracks from Bunbury Canyon 2150 m, d) spiral worm tracks from Bunbury Canyon 2150 m possibly made by acorn worms (Phylum Hemichordata), e) burrow and mounds from Mentelle slope 1290 m typical of some shrimps , f) small (10-20 cm) crators from Geographe Canyon 1515 m depth.*

7.5 TYPES OF BIOTA AND ENVIRONMENTS RECORDED FROM MENTELLE BASIN AND VLAMING SUB-BASIN

7.5.1 Mentelle Basin

7.5.1.1 Data

Seven stations were sampled from the Mentelle Basin during the SS07/05 and SS10/05 surveys: 2 video transects, 2 benthic sleds, and 3 grab samples were collected from the 400 m isobath (CSIRO unpublished report) (Table 7.4, Figure 7.11a). In addition 100 still photographs were taken within the Mentelle Basin from two slope and six canyon stations during Geosciences Australia's SS08/05 survey (GA unpublished report) (Figure 7.11a).

SS08/05, Mentelle (slope), cam 03, lat -32° 53.30', lon 114° 12.59', still photos x36, depth 1290 m
SS08/05, Mentelle (slope), cam 08, lat -32° 37.31', lon 114° 25.27', still photos x11, depth 1090 m
SS08/05, Mentelle (BsC), cam 02, lat -32° 31.11', lon 114° 19.56', still photos x 1, depth 2369 m
SS08/05, Mentelle (BsC), cam 09, lat -32° 35.30', lon 114° 21.73', still photos x 9, depth 1665 m
SS08/05, Mentelle (BsC), cam 10, lat -32° 31.72', lon 114° 18.36', still photos x 9, depth 2764 m
SS08/05, Mentelle (GC), cam 07, lat -32° 51.43', lon 114° 14.95', still photos x13, depth 1515 m
SS08/05, Mentelle (BuC), cam 04, lat -32° 49.39', lon 113° 51.48', still photos x16, depth 2594 m
SS08/05, Mentelle (BuC), cam 06, lat -32° 59.26', lon 113° 53.62', still photos x 5, depth 2150 m

… where BsC=Busselton Canyon, BuC=Bunbury Canyon, GC=Geographe Canyon, and lat, lon, and depth= starting positions and starting depth.

Table 7.4: Sampling undertaken at locations and depths within the Mentelle Basin during the SS07/05 and SS10/2005 survey. Values in the depth column represent station numbers. Table modified from (CSIRO unpublished report).

Sites	Gear type	100m	200m	400m	700m	1000m	1100m
Mentelle	sled						
slope	grab			156-158			
	video			155			
Mentelle	sled			13			
Bunbury Canyon	Beam trawl			67			
	video			154			

7.5.1.2 Habitat and Biotic Description for Mentelle

Mentelle Basin covers an area of 36,400 km^2 and ranges in water depth from 200 m just below the shelf break (SB) to 4,000 m that comprise continental slope and deep canyon habitats (Figures. 7.10, 7.11, 7.12, and 7.13). The continental slopes of Mentelle appear to be characterized by sandy-mud sediments rich in carbonates.

While four canyons were mapped within the Mentelle basin, sediment samples were only recorded from Bunbury Canyon. Still photographs were recorded from three of the four canyons (Busselton Canyon, Bunbury Canyon, and Geographe Canyon). Video footage (SS07/05 stn 155) and grab samples (SS07/05 stn 156, 157, 158) on the slope and video footage (SS07/2005 stn 154), and benthic sleds

(SS07/05 stn 13, 67) and still photographs from a range of sites (SS08/05) down Bunbury Canyon.

These images identified most stations as characterized by fine sandy mud sediments with flat relief and low to moderate bioturbation. These areas had a variety of different bioturbators from finely patterned thread-like tracks (Figure 7.10a,c) and starburst bioturbation patterns (Figure 7.10b), to activities resulting in pits, spiral-tracks (*probably from acorn worms* (*Phylum Hemichordata*)) (Figure 7.10d), burrows, mounds (*possible from burrowing shrimps*) (Figure 7.10e), and crators (Figure 7.10f).

In contrast to regular infaunal activity, epifaunal organisms were rare and sparsely distributed (e.g. Figure 7.12a,c). These included a small starfish, unknown foliose invertebrate (probably a sponge), several solitary anemones/zooanthids. Demersal species were also rare with 2 demersal shrimps, a rattail fish, and 2 catsharks recorded (CSIRO and GA unpublished survey reports).

No hard outcrops on either slopes or canyons within Mentelle Basin were recorded during these surveys (SS07/2005 and SS08/2005). However, a station immediately above Mentelle Basin - at the head of Bunbury Canyon in 100 m water depth - comprised approximately 60% hard substratum with a thin veneer of fine mud that was covered in bryozoans, sponges, and soft corals (Figure 7.13a), while the remaining 40% of the seafloor at this station was characterized as rippled fine mud sediments (CSIRO unpublished report).

Multibeam and seismic data within Mentelle suggests that rock outcrops occur in areas of steep canyon walls (Chapter 4 and 5). While sedentary fauna such as sponges, bryozoans and gorgonians probably occur in these habitats no data within Mentelle is available to confirm this. The deepest biological information recorded from Mentelle Basin was a series of nine still photographs from 2764 m in Busselton Canyon. Here sediments were sandy mud flat relief with some bioturbation in the form of tracks and starburst patterns (Figure 7.10b) with high occurrence but low numbers of a solitary ball-shaped sponge. No biological samples were recorded from the abyssal plains (>4,000 m depth).

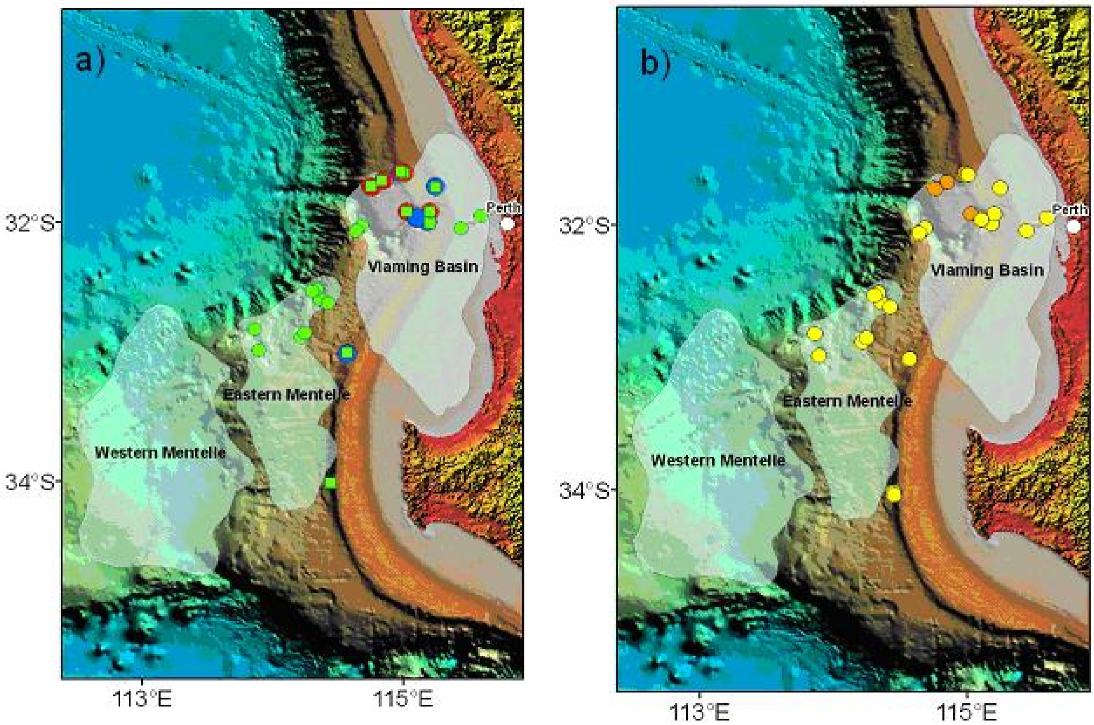


Figure 7.11: *Maps of Vlaming Sub-Basin and Mentelle Basin showing areas sampled during SS07/2005, SS08/2005, and SS10/2005. a) location and types of samples collected: towed video camera (green squares), still photography (green circles), benthic sleds (red circles), and beam-trawls (blue circles). b) the seafloor bottom type (yellow circles=soft sediment, orange circles=hard bottom) and locations sampled.*

7.5.2 Vlaming Sub-Basin

7.5.2.1 Data

Twenty-one stations were sampled from the Vlaming Sub-Basin during the SS07 2005 survey: 8 video transects, 8 benthic sleds, and 5 beam-trawls were collected from a range of 6 depths (Table 7.5, Figure 7.11a). In addition, 19 still photographs were taken within the Vlaming Sub-Basin from three stations within the Perth Canyon during Geoscience Australia's SS08/05 survey (GA unpublished report). Descriptions are also based on unpublished information provide by CSIRO.

SS08/05, Vlaming (PC), cam 11, lat -32° 03.69', lon 114° 38.20', still photos x7,depth 1280 m
SS08/05, Vlaming (PC), cam 12, lat -32° 03.01', lon 114° 38.92', still photos x1,depth 2035 m
SS08/05, Vlaming (PC), cam 13, lat -32° 01.68', lon 114° 40.87', still photos x11,depth 2680 m

… where PC=Perth Canyon, and lat, lon, and depth= starting positions and starting depth.

Table 7.5: Sampling undertaken at locations and depths within the Vlaming Sub-Basin during the SS07/05 and SS10/2005 survey. Values in the depth column represent station numbers (modified from CSIRO unpublished report).

Sites	Gear type	100m	200m	400m	700m	1000m	1100m
Vlaming	sled		69	12			72
Perth Canyon	beamtrawl				68	73,71	
	video		218	216	217		
Vlaming	sled		11	6	7	9,10	
Two Rocks	beamtrawl	2		4			
	video	219	129	150	149	148	

7.5.2.2 Habitat and Biotic Description for the Vlaming Sub-Basin

The Vlaming Sub-Basin covers an area of 23,000 km^2 ranging in water depth from 0 m on land to 3,000 m that encompasses nearshore coastal, continental shelf, continental slope, and deep canyon habitats (Figures. 7.11, 7.12 and 7.13). In the nearshore, intertidal and subtidal platform reefs are narrow alongshore (0-20 m), and composed of limestone ridges and reefs. These nearshore habitats are characterised by important habitats such as extensive seagrass meadows, limestone ridges and reef platforms that support highly diverse coral reef assemblages (Veron, 2000). The continental shelf of Vlaming Sub-Basin is characterized by coarse sands with small fragments of shell material (Chapter 5) with some areas of low-lying limestone reefs (Chapters 4, 5). The width of the continental shelf within the Vlaming Sub-Basin varies from 4 km in the north to 6 km in the south (Figure 7.11), with the shelf break (SB) consistently located at approximately 170 m water depth. Sand ripple and sand wave habitats have also been mapped on the shelf at the head of the Perth Canyon (Chapter 4 and 5) and on the shelf above Two Rocks (Figure 7.12d). In the troughs of sand waves pieces of hard rubble were encrusted with sponges and other encrusting fauna, while sand ripple habitats had no visible fauna. Like Mentelle Basin, the continental slope of Vlaming Sub-Basin was characterized by bioturbated fine sandy mud sediments.

The major bathymetric feature within the Vlaming Sub-Basin is the Perth Canyon (Figure 7.11). This is an area of localized upwelling. Samples taken at three depths (200 m, 400 m, and 700 m) characterize the seafloor as bioturbated fine mud sediments (CSIRO unpublished report). At 200 m these fine bioturbated mud sediments were inhabited with occasional patches of branched sponges (Figure 7.13e).

At 400 m these fine bioturbated mud sediments with sparsely populated delicate branching soft corals and soft bryozoan, were interspersed with small patches of high-relief rocky outcrops (Figure 7.13d), which on the northern flank of the canyon comprised 30% of the available habitat. These rocky outcrops are inhabited by a variety of crinoids, sponges, and sea-whips (CSIRO unpublished report).

At 700 m fine bioturbated mud sediments were inhabited by the occasional solitary anemones/zooanthids, and crinoids. The deepest biological information recorded from the Perth Canyon was a series of eleven still photographs from

2680 m. Here the seafloor was composed of fine sandy mud (Chapter 5) flat relief with low intensity but high occurrence of bioturbation in the form of tracks, burrows, and small mounds (e.g. Figure 7.10b) and the common presence of solitary ball-shaped sponges - also found at similar depths in the Mentelle Basin.

Immediately north of Perth Canyon lies a location called 'Two Rocks' (31º36' - 31º44' S and 114º45' - 115º15' E). Samples taken at five depth zones (100 m, 200 m, 400 m, 700 m, and 1,000 m) characterized the seafloor as bioturbated fine mud sediments with patches of rock outcropping (ranging from ~5-50% of each video transects) (CSIRO unpublished report). Specifically: at 100 m rippled sandy sediments with no epifauna comprised 70% of the seafloor Figure 7.12d) interspersed with 30% hard substrata supporting corals and sponges.

At 200 m homogeneous bioturbated mud sediments supported finger and fan sponges and soft bryozoan. At 400 m 95% of the seafloor was bioturbated fine mud sediments interspersed by rocky outcrop (5%) covered in a diverse fauna of bryozoan thickets, branching sponges and whip corals. At 700 m 90% of the seafloor was bioturbated fine mud sediments with occasional solitary ball-shaped sponges (Figure 7.12f) interspersed by patchy outcrops (10%) that supported reef-building corals (Figure 7.13c). Finally, at 1,000 m – the deepest location sampled - bioturbated fine mud sediments comprised ~75% of the seafloor, ~10% rocky outcrop (Figure 7.13b,f) with small patches of crinoids, coral and anemones and ~5% cobbles representing areas of debris flow with no visible fauna.

7.6 KEY DATA GAPS

Past surveys undertaken by CSIRO and Geoscience Australia provide a vital first glance on the types of habitats and biota that exist in the deep (slope-abyssal) waters off Western Australia, as well as providing valuable information on specific areas and depths. These studies, in combination with those more detailed studies on similar assemblages of the north-west slope, provide valuable insight into the probable assemblage types and function of the Mentelle-Vlaming ecosystem.

However, understanding the relative contributions of depth, seafloor type and sediment composition in structuring benthic assemblages within the Mentelle Basin and Vlaming Sub-Basin requires geophysical and biological samples to be collected more systematically from a range of depths and habitats. Little direct information is known on the functional relationship between organisms within deep-sea benthic food webs off Western Australia. The inclusion of stable isotope methods within a deep-sea sampling framework may identify the critical links in these benthic systems and may help to understand the health and resilience of these valuable deep-sea ecosystems.

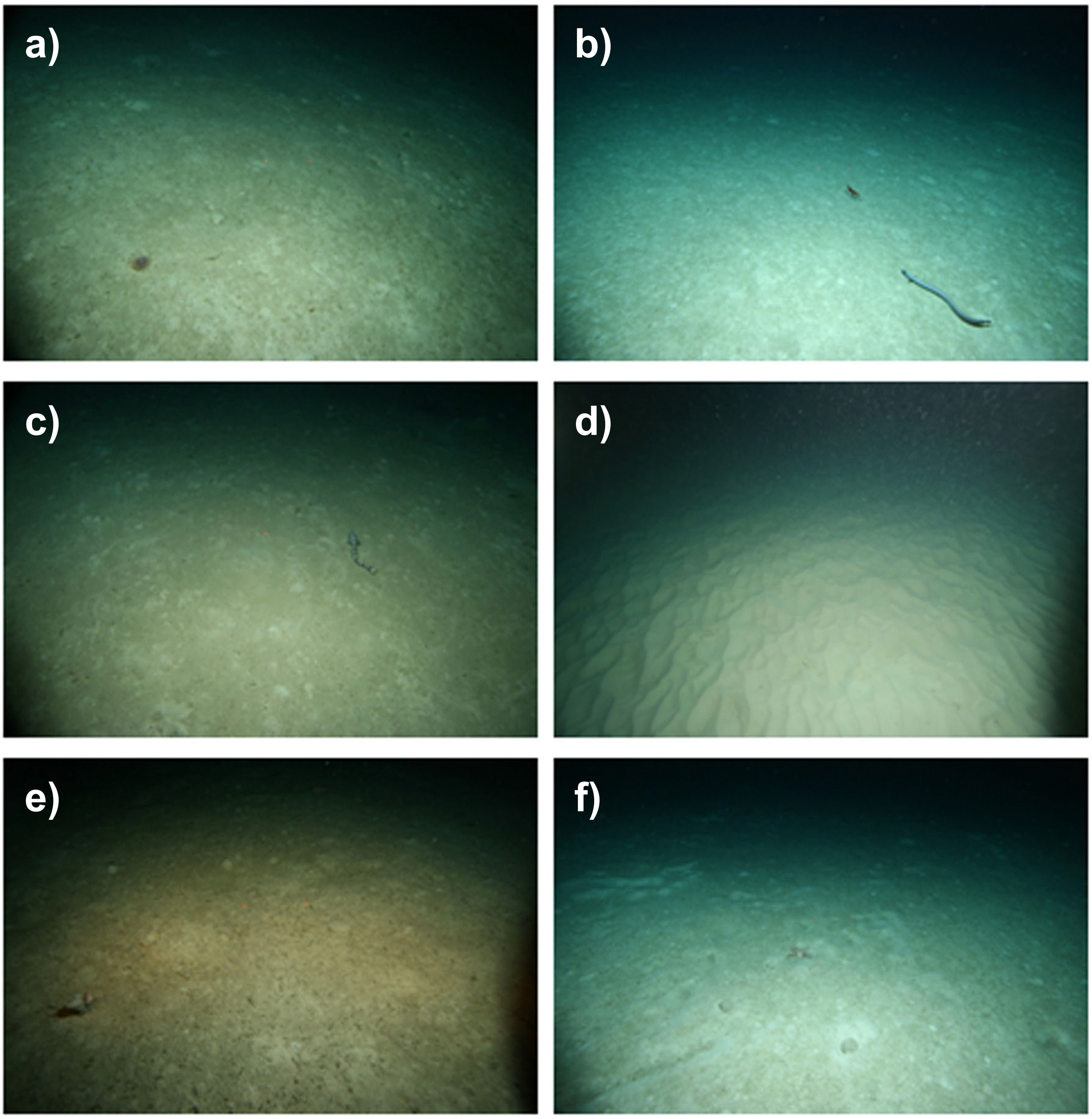


***Figure 7.12**: Still colour photographs of shelf, slope, and canyon habitats from the Vlaming Sub-Basin and Mentelle Basin habitats collected during CSIRO Wealth from Oceans flagship Voyage of Discovery surveys (SS07/2005 and SS10/2005). a) Mentelle: Slope 400 m - bioturbated sediments with solitary anemone, b) Vlaming: Two Rocks 1,000 m – bioturbated sediments with eel-like fish and shrimp, c) Mentelle: Bunbury Canyon 400 m – bioturbated sediments with small catshark, d) Vlaming: Two Rocks 100 m – sand ripples, e) Vlamming: Perth Canyon 700 m – bioturbated sediments showing squat lobster sheltering against a solitary sponge, f) Vlaming: Two Rocks 700 m – bioturbated sediments with crab and solitary ball-shaped sponges. Photos provided by CSIRO Wealth from Oceans flagship Voyage of Discovery.*

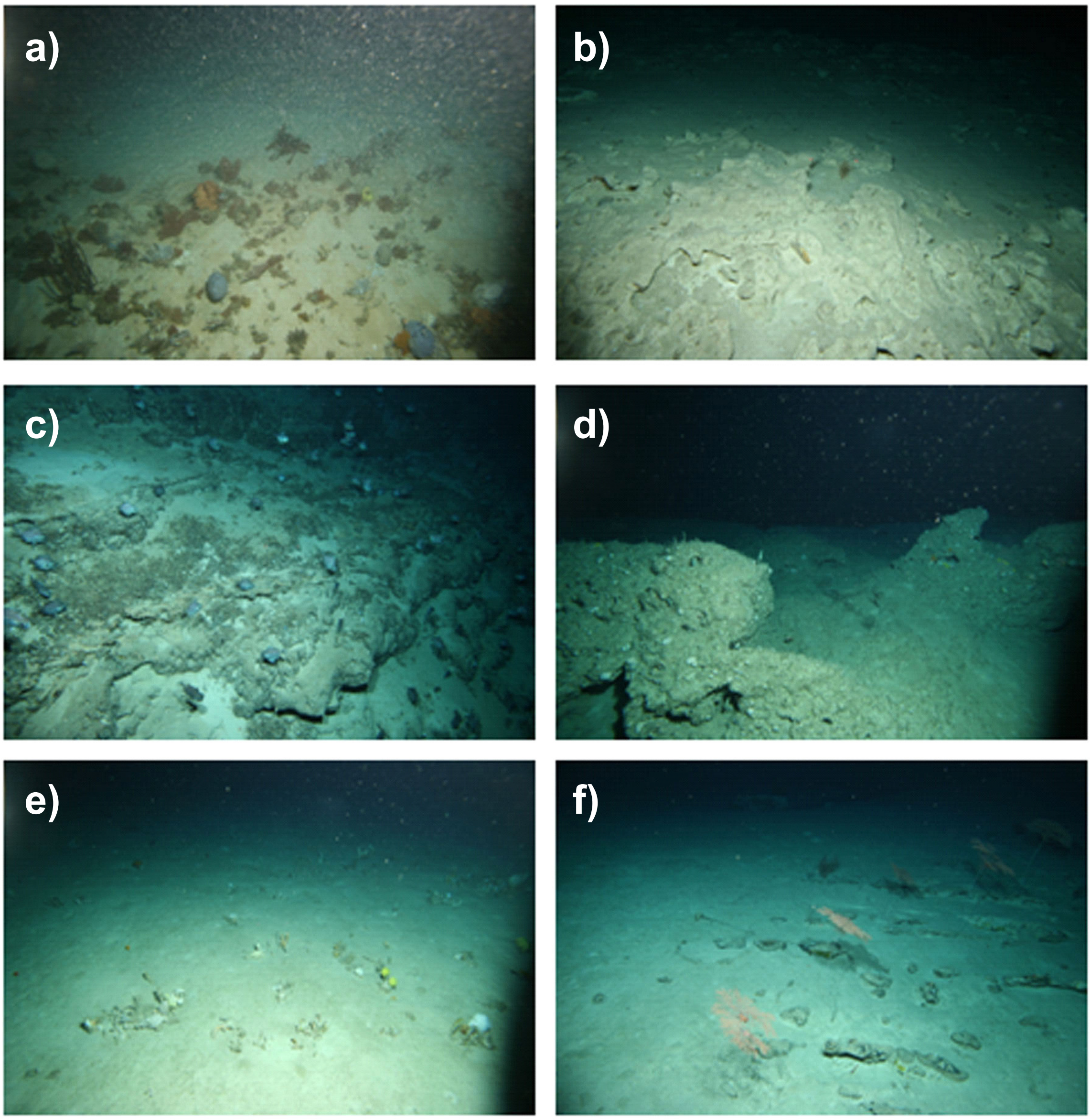


Figure 7.13*: Still colour photographs of shelf, slope, and canyon habitats from Vlaming Sub-Basin and Mentelle Basin habitats collected during CSIRO Wealth from Oceans flagship Voyage of Discovery surveys (SS07/2005 and SS10/2005). a) Mentelle: Bunbury Canyon 100 m - hard substratum with a thin veneer of fine mud sediments covered in bryozoans, sponges, soft corals, and filamentous red algae, b) Vlaming: Two Rocks 1,000 m – low-relief outcrop with delicately branched soft corals, c) Vlaming: Two Rocks 700 m – A large school of juvenile Oreo Dories associated with exposed bedrock ridges, d) Vlaming: Perth Canyon 400 m – high-relief limestone reef, e) Vlaming: Perth Canyon 200 m – sponge field, f) Vlaming: Two Rocks 1,000 m – patchy rock outcrop (possibly bedded sedimentary rock) with long-armed Ophiuroids (brittlestars) entwined in tree-like gorgonians. Photos provided by CSIRO Wealth from Oceans flagship Voyage of Discovery.*

8. Seascapes

8.1 INTRODUCTION AND DATA SOURCES

One of the biggest challenges facing marine scientists is the development of a robust and defensible way to represent potential seabed habitats and ecosystems, based on easily mapped and spatially-abundant biophysical properties. Geoscience Australia has undertaken a classification of biophysical datasets to create seabed habitat maps or 'seascapes' for Australia's marine region. Seascapes describe a layer of ecologically-meaningful biophysical properties that spatially represents potential seabed habitats (Figure 8.1). Each seascape corresponds to a region of seabed that contains similar biophysical properties and by association similar seabed habitats and communities. Maximum seabed biodiversity is assumed to coincide with maximum seabed habitat heterogeneity, which is likely to occur in regions of maximum seascape diversity. The procedure for creating the seascapes is inspired by the shelf classification applied in eastern Canada by Roff & Talyor (2000) and Roff et al. (2003) and has been adapted by Geoscience Australia for Australia's marine region (Whiteway et al., 2007).

The assumption that biophysical properties can be used as surrogates to represent marine biodiversity is central to the seascapes approach. While linkages between the biophysical environment and biota seem intuitive, understanding how the biota relates to biophysical physical properties is only half the story. It is equally important to identify which biophysical properties are important. Biophysical variables that are most suited to deriving seascapes are those that are easily quantified, have a wide distribution, and a known and measurable association with the biota (Post, 2008; Bax & Williams, 2001). Given the availability and distribution of common datasets for Australia's marine region, separate seascapes were derived for the shelf (on-shelf) and slope, rise and abyssal plain/deep ocean floor (off-shelf) environments due to an extra dataset being available for the shelf (Table 8.1). All data were interpolated from point data and gridded at 0.05° (~5 km) resolution to provide 100% coverage of the sea floor.

Table 8.1: Datasets used in the derivation of the seascapes.

Dataset	Units
On-shelf	
Water depth	(m)
Sea Floor Temperature	(°C)
% Gravel	(weight %)
% Mud	(weight %)
Primary Production	(mg C m^{-2} day^{-1})
Slope (rugosity)	(°)
Effective disturbance	(Non-dimensional)
Off-shelf	
Water depth	(m)

Sea Floor Temperature	(°C)
% Gravel	(weight %)
% Mud	(weight %)
Primary Production	(mg C m^{-2} day^{-1})
Slope (rugosity)	(°)

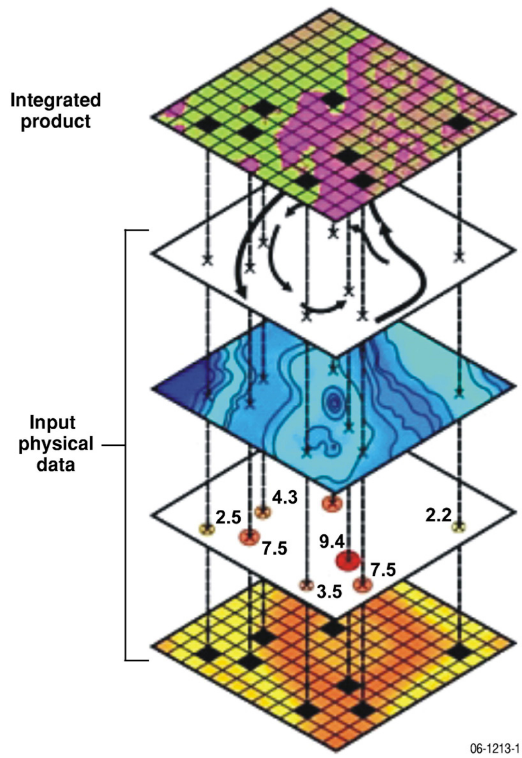


Figure 8.1: *Schematic diagram showing derivation of seascapes from multiple spatial layers of biophysical data. The seascapes represent the integrated product of the individual datasets (From Whiteway et al., 2007).*

Hierarchical classification schemes have the intrinsic predictive power of describing the relationships between physical habitats and their associated biological communities. Roff and Taylor (2000) suggest that a hierarchical classification scheme is essential for the selection of representative or distinctive habitats. This has prompted the development of a number of different classification schemes and recognition that marine regions can be divided into the following broad hierarchical units (for example):

Provinces
Biomes
Geomorphic Features
Biotopes

Other equally valid terms may be used in place of these and there is any number of possible different divisions in the hierarchy. However, the above hierarchical scheme can be used to guide the derivation of the seascapes for Australia's marine region.

8.2 CLASSIFICATION METHODOLOGY

Below is summary of the classification methodology used by Geoscience Australia for deriving the seascapes. A full description of the methodology can be found in Whiteway et al. (2007).

8.2.1 Unsupervised Classification

The seascapes were classified using the Iterative Self Organising Classification (ISOclass) methodology in the software package ERMapper. This methodology is an unsupervised crisp classification meaning that the classification is run without any user input to help define the classes and each data point can only belong to one class.

There are several solutions to finding the final classification and selecting the optimal number of classes and location of the best class boundaries is essential. Statistically, there will be an optimal number of classes into which the data can be divided that will minimise the uncertainty.

For the purposes of deriving the seascapes for Australia's marine region, the optimal number of classes (i.e., seascapes) was identified using the distance ratio method. The distance ratio is the ratio of the average of the mean distance of each class member from its class mean to the overall average distance of each member from the overall mean. The distance ratio gives an indication of how good the classification is, in that the smaller the value, the closer on average the individual class members are to their class means. For the purposes of deriving the optimum number of seascapes for Australia's marine region, a plot of distance ratio versus number of classes was calculated for a range of 3 to 20 classes.

The optimal number of seascapes was determined from the distance ratio graph as a local minimum; usually taken as the first local minimum before the overall gradient of the graph begins to decrease (Figures. 8.2 & 8.3). In making the final decision, the distribution and make-up of the classes corresponding to the local minimum were compared with the broad-scale knowledge of the geology and ecology of the marine region.

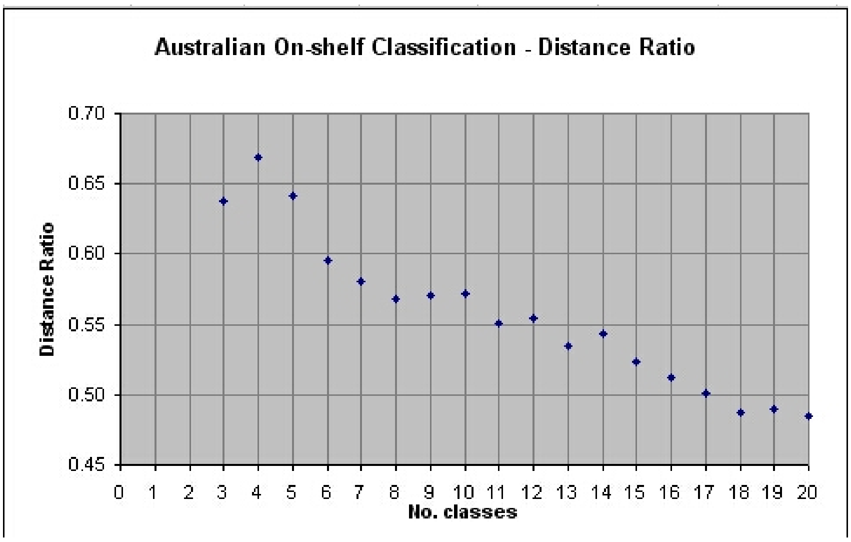


Figure 8.2: Distance ratio graph for the on-shelf classification. A total of 13 seascapes were defined for the on-shelf region based on the local "minimum" of the series. This minimum was also chosen because it provides for an ecologically-meaningful classification and has the greatest difference between adjacent class solutions.

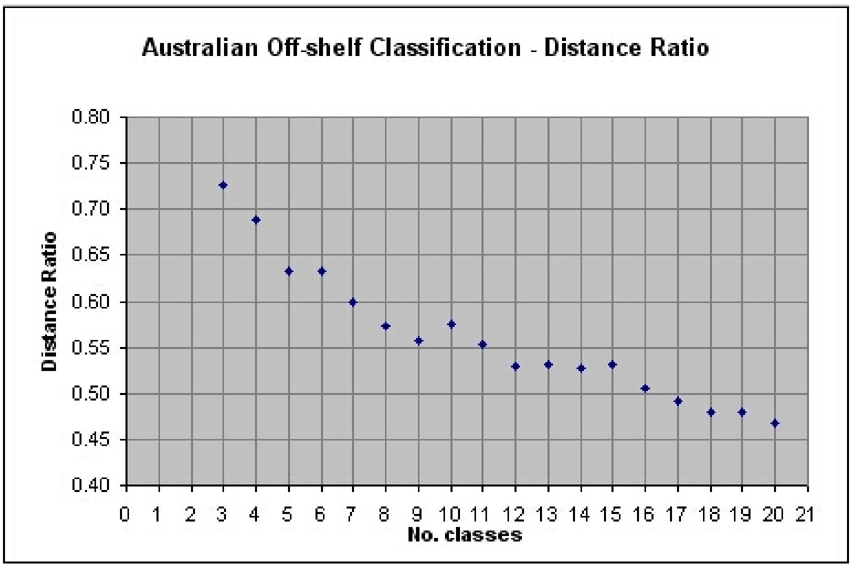


Figure 8.3: Distance ratio graph for the off-shelf classification. A total of 9 seascapes were defined for the off-shelf region based on the local "minimum" of the series. This minimum was also chosen because it provides for an ecologically-meaningful solution and represents the point where the gradient of the graph diminishes and increasing the number of seascapes results in relatively small decreases in the distance ratio.

8.2.2 Seascape Names

The seascapes are named with reference to the hierarchical scheme outlined in Section 8.1. At the scale of provinces and biomes, water depth is the most important variable. A plot of the mean and standard deviation values of water depth allows each of the on-shelf and off-shelf seascapes to be ranked in terms of increasing water depth (Figures. 8.4 & 8.5). At the scale of geomorphic features, correlation of the seascapes with the geomorphic features map of Australia's margin (Heap & Harris, 2008) provides an independent check on seascape character and spatial extent. After depth, the seascapes are named using geomorphic features that comprise >25% of the area of each of the seascapes, except for on-shelf seascapes 2, 6 and 8 and off-shelf seascape 4, where the feature with the highest percent area covered is used (Table 8.2). Finally the seascapes can be ranked using the mean values of the remaining physical properties. Where a seascape is ranked in the top or lowest three of the mean values for any of the physical properties then that property is included as a descriptor for the seascape (Table 8.3).

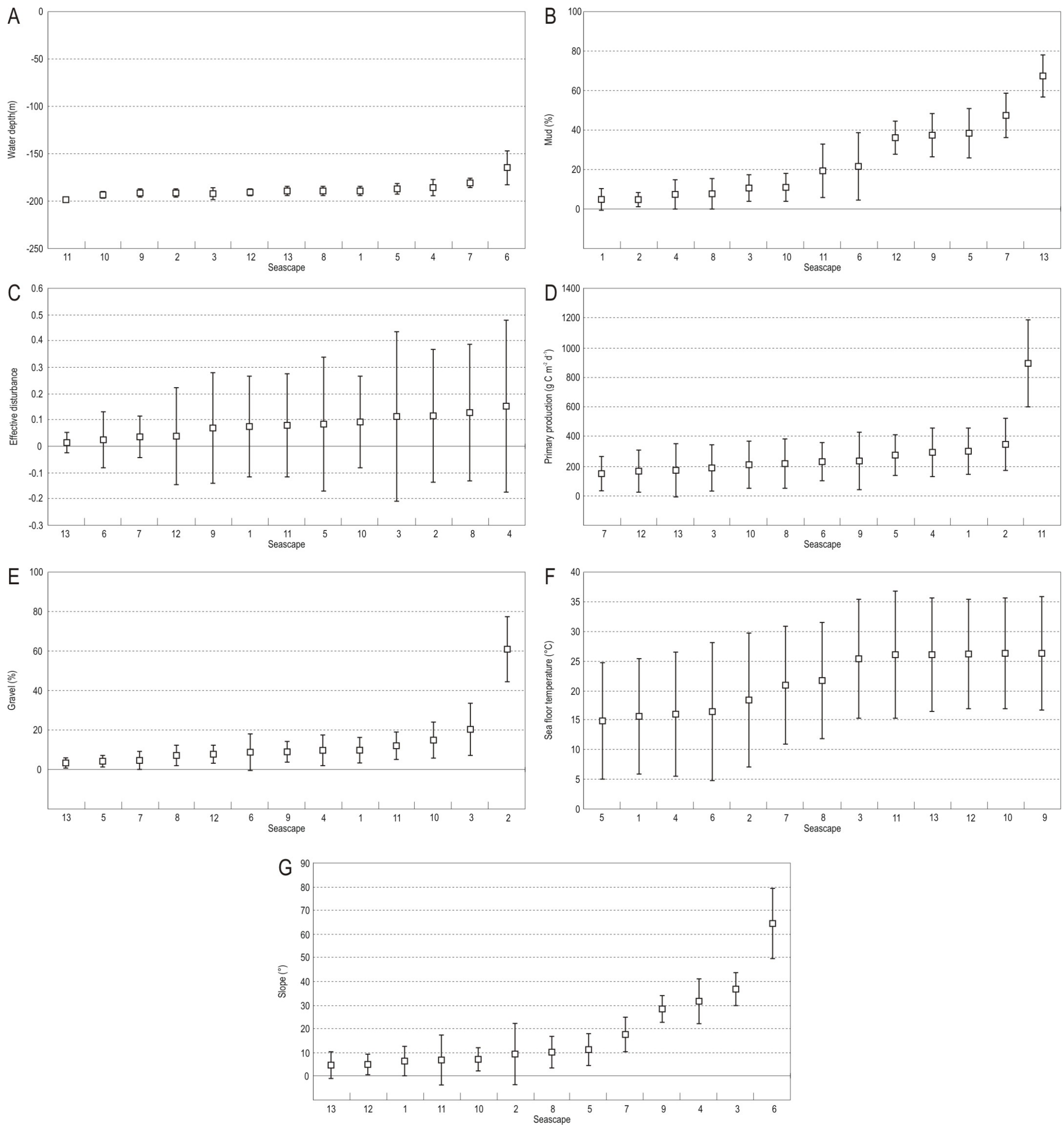


Figure 8.4: *Graphs of seascape versus: (A) water depth; (B) mud content; (C) effective disturbance; (D) primary production; (E) gravel content; (F) sea floor temperature; and (G) slope for the on-shelf seascapes of the Australian margin. Physical properties with the three highest and lowest mean values are used as*

distinguishing properties in naming each of the seascapes. Plots show means and limits of one standard deviation.

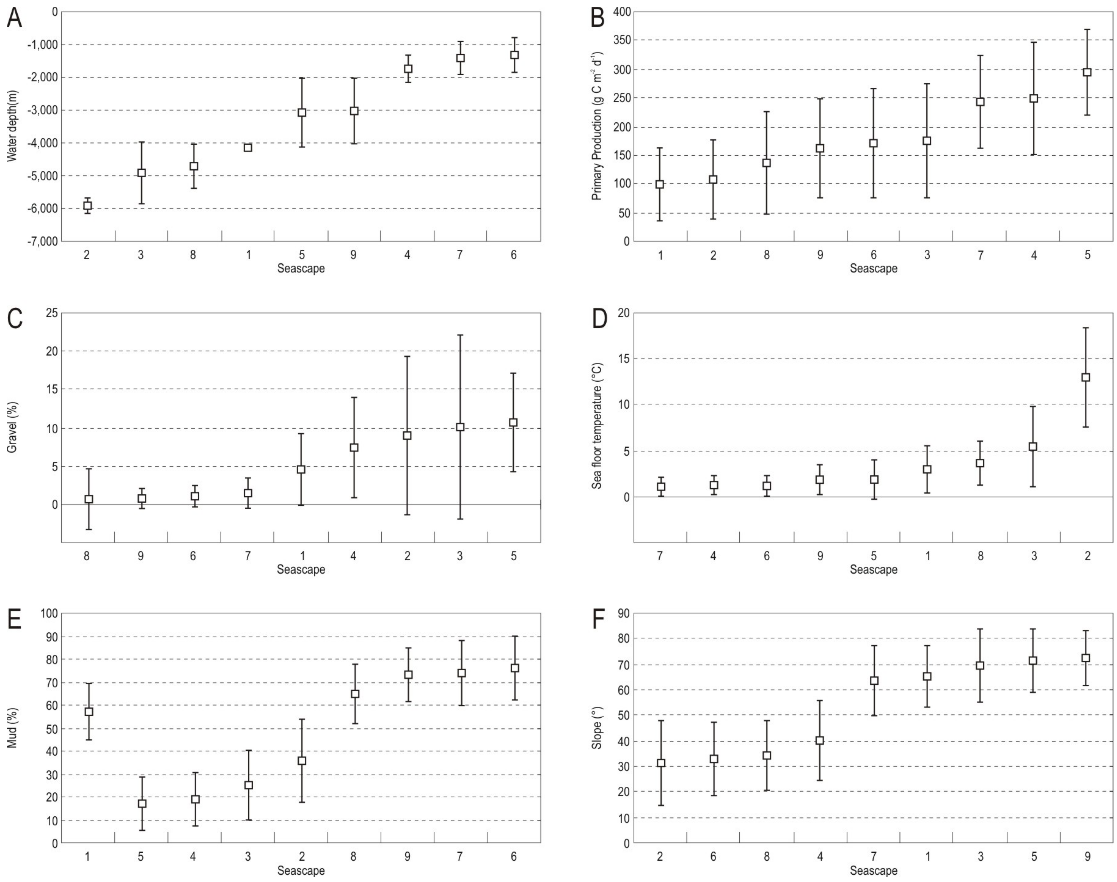


Figure 8.5: *Graphs of seascape versus: (A) water depth; (B) primary production; (C) gravel content; (D) sea floor temperature; (E) mud content; and (F) slope for the off-shelf seascapes of the Australian margin. Physical properties with the three highest and lowest mean values are used as distinguishing properties in naming each of the seascapes. Plots show means and limits of one standard deviation.*

Table 8.2: Percentage of geomorphic feature (from Heap & Harris, 2008) comprising the total area each of: a) on-shelf and b) off-shelf seascapes for the Australian margin. Highlighted cells identify the geomorphic features used to characterise each seascape.

a) On-shelf seascapes

	Seascape												
Feature	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Abyssal plain/deep ocean floor	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Apron/fan	0.00	2.04	1.55	1.22	15.71	2.53	65.31	10.34	1.29	0.00	0.00	0.00	0.00
Bank/shoals	3.31	0.16	16.98	0.73	0.04	0.31	0.65	1.59	26.50	15.27	0.70	20.56	13.20
Basin	2.82	0.08	0.92	0.07	4.01	0.14	1.16	0.00	1.61	9.91	0.84	44.02	34.40
Canyon	0.00	0.08	1.99	0.59	3.23	7.68	57.04	10.92	2.79	0.29	0.00	1.93	13.46
Continental rise	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Deep/hole/valley	19.04	0.29	9.95	3.64	5.62	1.35	11.21	11.34	8.44	13.87	1.12	9.60	4.55
Escarpment	20.46	0.00	0.00	35.70	25.69	18.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Knoll/abyssal-hills/hills/mountains/peak	73.09	0.00	0.00	19.13	4.80	2.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pinnacle	1.18	0.00	13.61	5.02	0.29	3.08	12.72	3.84	19.04	5.50	0.00	9.96	25.76
Plateau	19.57	1.28	31.72	4.36	1.84	0.41	0.05	0.15	5.72	27.15	0.47	7.26	0.03
Reef	0.54	1.35	47.69	0.93	0.02	1.95	0.29	2.61	25.07	13.85	1.41	2.59	1.70
Ridge	0.00	0.44	8.46	0.90	0.33	4.50	50.23	21.49	8.49	3.69	0.00	0.33	1.14
Saddle	0.00	0.00	2.82	0.00	0.00	0.00	0.44	1.04	7.89	34.37	0.00	36.04	17.40
Seamount/guyot	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shelf	20.67	1.57	2.61	4.90	3.92	0.94	1.06	9.21	3.34	22.34	7.82	11.46	10.16
Sill	15.26	1.61	0.38	0.29	0.01	0.00	0.00	0.00	0.26	9.56	0.00	42.15	30.48
Slope	1.11	0.42	10.40	17.90	1.03	22.82	20.56	18.67	5.16	1.11	0.02	0.72	0.08
Terrace	18.33	0.30	5.47	2.76	2.43	3.39	6.76	7.67	6.28	24.13	0.76	16.10	5.62
Tidal-sandwave/sand-bank	26.97	1.83	2.42	5.74	0.01	0.00	0.00	0.54	3.08	18.36	32.68	2.07	6.29
Trench/trough	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

b) Off-shelf Seascapes

	Seascape								
Features	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Abyssal plain/deep ocean floor	4.28	0.00	0.26	24.63	3.81	35.82	25.16	0.54	5.51
Apron/fan	27.18	48.05	21.89	0.00	0.00	0.00	0.00	2.88	0.00
Bank/shoals	0.00	8.59	0.77	9.60	56.05	0.00	24.98	0.00	0.00
Basin	14.99	0.01	0.00	1.19	2.18	33.12	0.74	15.52	32.24
Canyon	4.40	1.65	11.25	0.56	34.66	0.17	8.26	2.14	36.92
Continental rise	12.50	0.00	4.28	4.35	0.00	45.93	8.64	0.00	24.31
Deep/hole/valley	26.69	7.60	5.33	0.00	0.01	9.80	7.50	29.21	13.87
Escarpment	0.00	0.00	3.90	0.39	46.36	2.79	15.55	0.00	31.01
Knoll/abyssal-hills/hills/mountains/peak	3.62	0.11	0.17	2.14	6.23	4.76	78.46	1.03	3.48
Pinnacle	19.27	6.62	3.67	4.17	30.24	3.59	12.44	0.72	19.27
Plateau	26.72	5.15	1.67	0.73	6.89	0.36	0.63	38.18	19.68
Reef	10.46	80.70	8.40	0.00	0.00	0.00	0.00	0.15	0.29
Ridge	3.17	0.08	0.46	0.97	14.09	0.31	77.16	0.74	3.01
Saddle	23.80	6.88	1.03	7.83	23.41	5.39	0.00	11.01	20.65
Seamount/guyot	29.71	0.18	12.30	1.96	20.49	0.32	0.42	0.67	33.95
Sill	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Slope	15.56	7.47	14.00	6.94	14.92	2.80	13.65	3.95	20.70
Terrace	21.51	13.51	26.63	0.05	1.10	0.02	0.65	22.42	14.11
Tidal-sandwave/sand-bank	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trench/trough	26.33	5.69	11.63	0.48	1.75	1.61	1.39	45.66	5.43

Table 8.3: Description of seascapes for the Australian margin.

Seascape	Description
On-shelf	
1	Shelf; knoll/abyssal-hills/hills/mountains/peak, tidal sandwave/sand bank; low mud; high primary production; cool; flat
2	Shelf; apron/fan; high effective disturbance; very gravelly; low mud; high primary production
3	Shelf; reef, plateau; gravelly; rugose
4	Shelf; escarpment; very high effective disturbance; low mud; cool; rugose
5	Shelf; escarpment; low gravel; muddy; cold
6	Shelf/upper slope; low effective disturbance; very rugose
7	Shelf; apron/fan, ridge; low effective disturbance; low gravel; muddy; very low primary production
8	Shelf; ridge; high effective disturbance
9	Shelf; bank/shoals, reef; very warm
10	Shelf; saddle, plateau; gravelly; warm
11	Shelf; tidal sandwave/sand bank; very high primary production
12	Shelf; basin, sill saddle; moderate primary production; cool; flat
13	Shelf; basin, sill, pinnacle; very low effective disturbance; very low gravel; very muddy; low primary production; very flat
Off-shelf	
1	Abyssal; seamount/guyot, apron/fan, plateau, deep/hole/valley, trench/trough; very low mud, very low primary production
2	Abyssal; reef, apron/fan; gravelly; low primary production; very warm, flat
3	Abyssal; terrace; high gravel; warm; rugose
4	Bathyal; abyssal plain/deep ocean floor; low mud, high primary production, cold
5	Abyssal; bank/shoal, escarpment, canyon, pinnacle; very gravelly, muddy; very high primary production; rugose
6	Bathyal; continental rise; abyssal plain/deep ocean floor, basin; low gravel; very muddy; cold; flat
7	Bathyal; knoll/abyssal-hill/hill/mountain/peak, ridge, abyssal plain/deep ocean floor; muddy; high primary production; very cold
8	Abyssal; trench/trough, plateau, deep/hole/valley; very low gravel; low primary production; warm; flat
9	Abyssal; canyon, seamount/guyot, basin, escarpment; low gravel; muddy; very rugose

8.3 SEASCAPES FOR THE AUSTRALIAN MARGIN

A total of 13 and 9 ecologically-meaningful seascape classes were derived for the on-shelf and off-shelf regions of the Australian margin, respectively (Figures. 8.6 & 8.7).

Complete descriptions for the national distribution of each of the 13 seascapes derived for the shelf are contained in Heap et al. (in press). Several trends in their occurrence and distribution can be discerned at a continental scale. Firstly, the on-shelf seascapes divide into two broad latitudinal groups (Figure 8.6). The southern group (seascapes 1-7, which mostly cover the Vlaming Sub-Basin region) is characterised by generally sandy, cooler environments relative to the northern group (seascapes 9-13) which is characterised by muddier, warmer environments and shallower water. Interestingly, seascapes dominated by gravel occur only on the southern margin. Additionally, the overall distribution of on-shelf seascapes appears to be more diverse and variable for the northern group, with significant heterogeneity over many parts of the shelf, particularly the central and northern Great Barrier Reef shelf and the outer Arafura and Sahul Shelves. Conversely, the distribution of on-shelf seascapes in the southern group is more uniform with each of the seascapes covering a relatively large area. Further work is required to determine if this difference in variability is a true reflection of the seascape distribution or merely a function of data density; more sediment samples are available for the northern margins.

On-shelf environments of the low-gradient and muddy shallow shelf basins of the Gulf of Carpentaria, Joseph Bonaparte Gulf, Gulf of Carpentaria and Bass Strait are represented by seascapes 13 and 5, respectively. On-shelf seascape 8 occurs predominantly on the west and east shelf regions and may represent a transitional environment between temperate and sub-tropical and tropical environments. On-shelf seascape 11 occurs along the coast, principally in the north, and is characterised by very high primary production (Figure 8.6). This appears to be an anomaly, as this zone is a region of elevated turbidity caused by river runoff, strong tidal and wave currents. This seascape, although correctly identified as a different region, is more likely to be a zone of high turbidity and relatively low primary productivity due to reduced light penetration to the bed.

Off the shelf, the distribution of seascapes lacks a distinct latitudinal pattern seen in the on-shelf seascapes and is more related to seafloor temperature as a function of depth (Figure 8.7). The seascapes are associated with a general decrease in grain size with depth and distance offshore. For the mid- to lower-slope, abyssal plain and deep ocean floor environments on the southern and western margins, seascapes are principally defined by slope (rugosity) and primary production. For other areas, seascape distribution is more complex, with bathymetry and slope (rugosity) emerging as key descriptors.

Nationally, off-shelf seascape 6 coincides with the vast, mostly sedimented, relatively flat abyssal plain environments around the margin. Where these deep-ocean environments have relief, including on the southern margin associated with margin spreading and in the vicinity of submarine canyons at the base of the slope, they are dominated by seascape 7. On the southeast margin, off-shelf seascapes 4 and 5 replace seascapes 6 and 7 as being the dominant types in the deep ocean. This may be a true change in seascape type, and the boundary south of Tasmania coincides with an ecological boundary based on demersal fish data (DEH, 2005). However, we note that relatively few sediment data were available for the deep southeast region, and it could be that the change in dominant seascape is a reflection of the paucity of sediment data in this region.

The following section draws on the continental-scale analysis of the seascapes presented in Heap et al. (in press) and emphasizes descriptions of the distribution and nature of those seascapes that are characteristic of the Vlaming Sub-Basin / Mentelle Basin region.

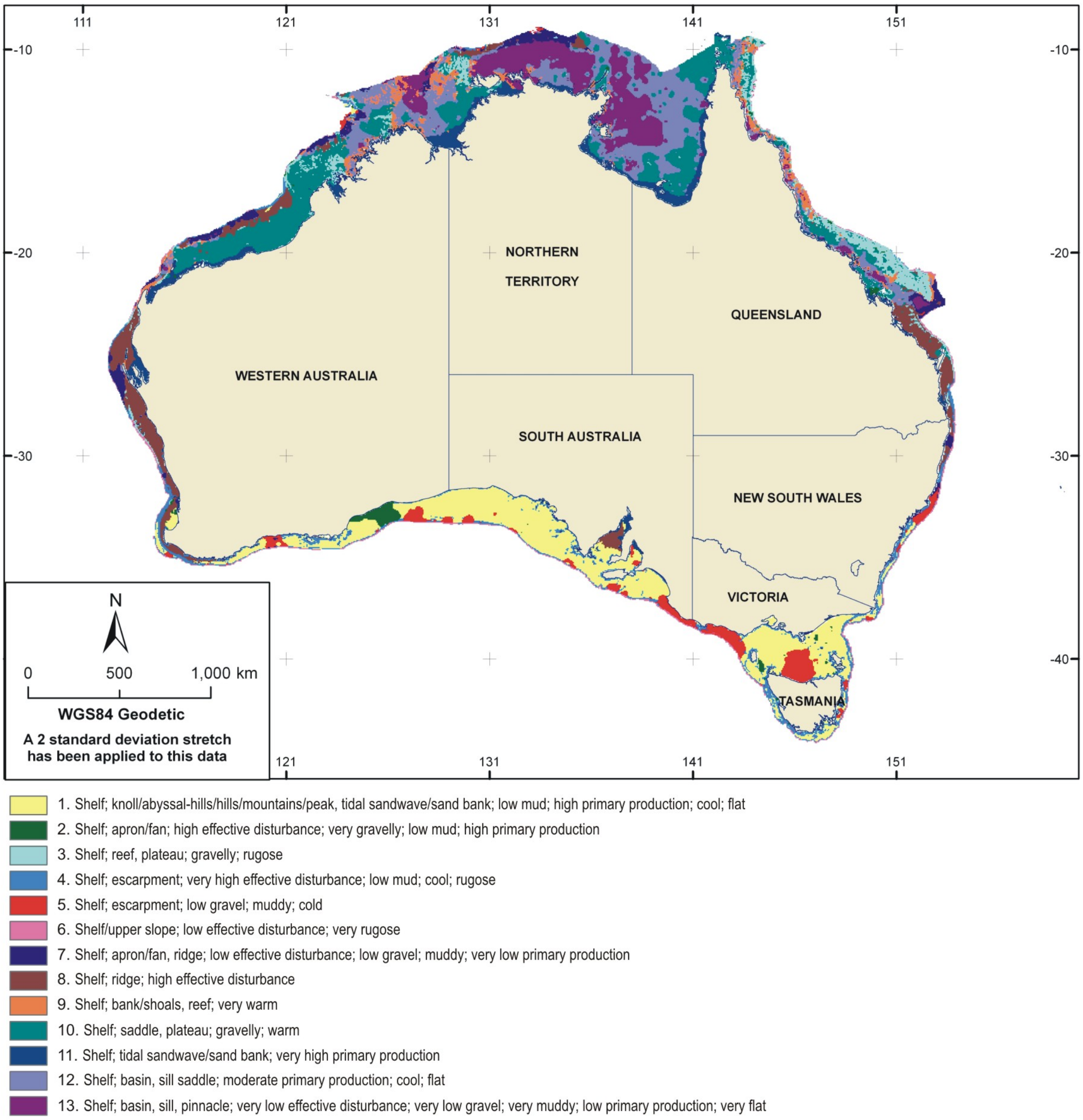


Figure 8.6: *Seascapes for the on-shelf region of Australia. The on-shelf seascapes can be divided into two latitudinal groups: a southern group (1-7) characterised by generally sandy, cooler environments and a northern group (9-13) characterised by muddier, warmer environments and shallower water, separated by a transitional seascape (9) on the west and east margins.*

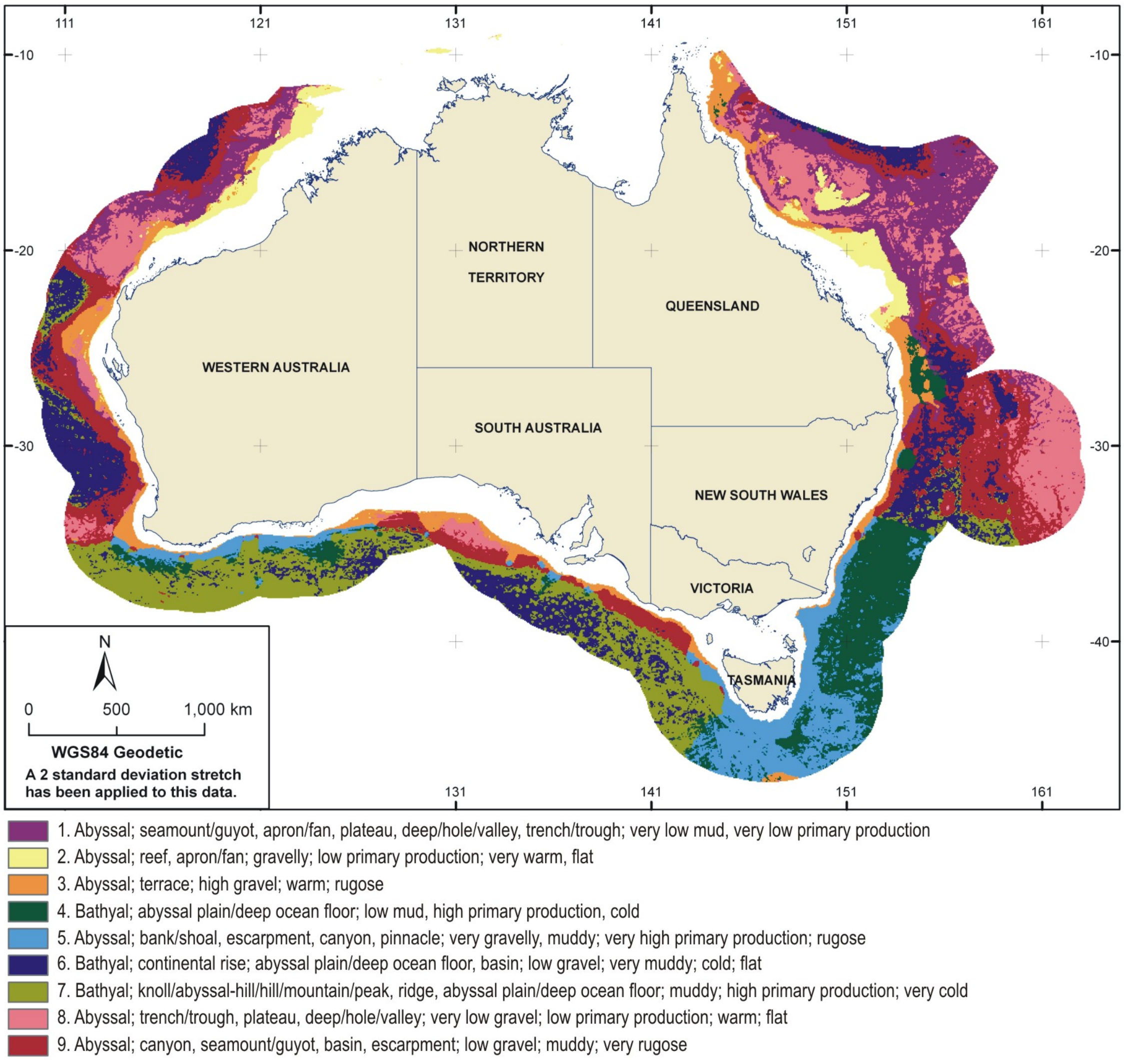


***Figure 8.7**: Seascapes for the off-shelf region of Australia. The distribution of off-shelf seascapes is complex, with bathymetry, slope (rugosity), sediment texture, and primary production emerging as key descriptors.*

A total of 8 on-shelf and 7 off-shelf seascapes occur in the Vlaming Sub-Basin / Mentelle Basin region (Figures. 8.8 & 8.9; Table 8.4). No on-shelf seascapes occur in the Mentelle Basin region.

Table 8.4: Area of on-shelf and off-shelf seascapes for the Vlaming Sub-Basin / Mentelle Basin region.

Seascape	**Area (km^2)**		
	Vlaming Sub-Basin	Mentelle Basin	Total
On-shelf			
1	1,730	-	1,730
2	590	-	590
3	130	-	130
4	3,240	-	3,240
5	-	-	-
6	410	-	410
7	120	-	120
8	5,590	-	5,590
9	-	-	-
10	-	-	-
11	20	-	20
12	-	-	-
13	-	-	-
Off-shelf			
1	640	190	830
2	30	-	30
3	2,350	5,060	7,410
4	-	100	100
5	-	60	60
6	-	1,950	1,950
7	-	-	-
8	400	3,750	4,150
9	1,530	18,210	19,740

8.3.1 On-shelf Seascapes

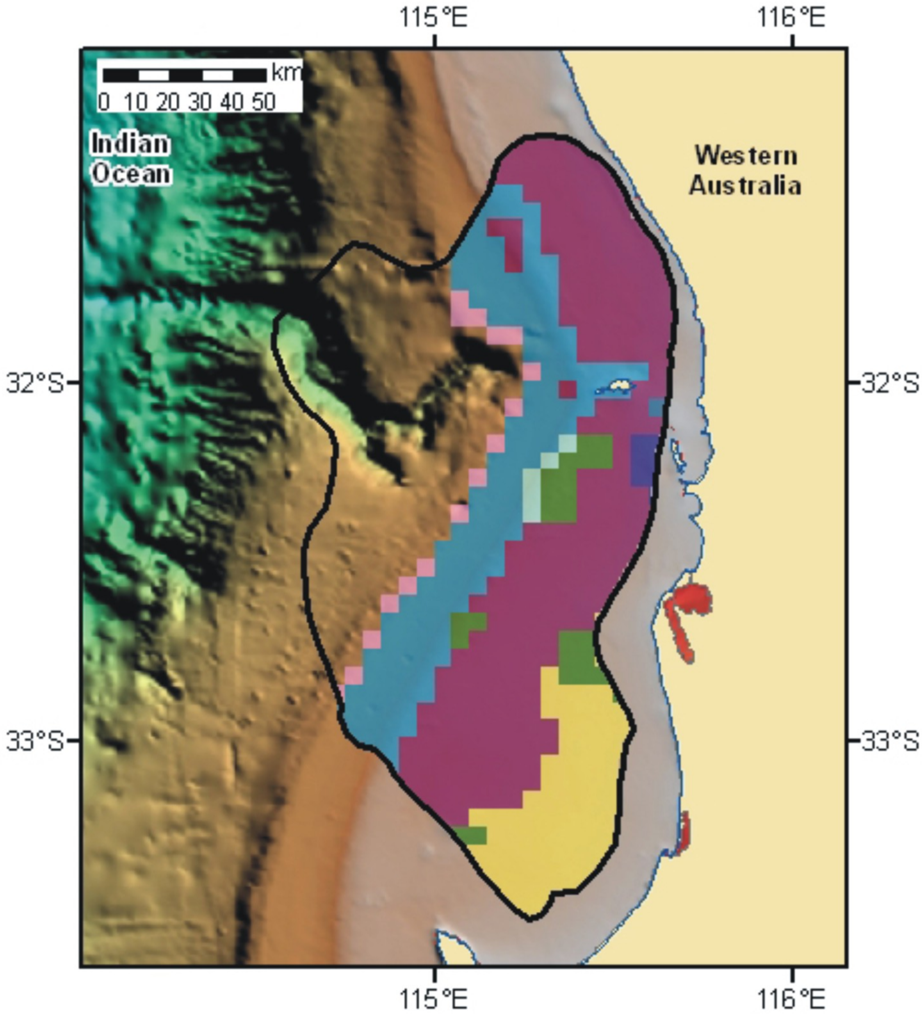
The dominant on-shelf seascapes (8, 4, 1 and 6) associated with the Vlaming Sub-Basin reveal a coast parallel distribution that is interspersed with the less dominant seascapes (2, 7, 3, 11) (Figure 8.8). This general coast-parallel distribution corresponds with the general seabed facies distribution on southern Western Australian shelf and reflects a decrease in grain size and increasing rugosity with depth. All of the on-shelf seascapes are located in water depths of <200 m and therefore they represent seabed environments of the upper-slope and shelf biomes.

Seascape 1 has a depth range of -184.75 to -193.91 m with a mean if -189.33 m (Figure 8.4). Nationally, it coincides with 73.09% knoll/abyssal-hills/hills/mountains/peak and 26.97% tidal-sandwave/sand bank geomorphic features (Table 8.2). It is also characterised by the lowest mud content, 3rd-highest primary production, 2nd-lowest sea floor temperature and 3rd-lowest slope values. In the Vlaming Sub-Basin, this seascape coincides with features on the middle and inner shelf (Table 8.2). It covers the 3rd-biggest area of the on-shelf seascapes in the basin (Table 8.4), and represents seabed environments that are only found in the southern part of the basin. Here, water depths associated with this seascape are relatively shallower than those characterised by the other seascapes in this basin (Figure 8.8).

Seascape 2 has a depth range of -187.80 to -196.12 m with a mean if -191.96 m (Figure 8.4). Nationally, it coincides with 2.04% apron/fan geomorphic features (Table 8.2). It is also characterised by 3rd-highest effective disturbance, highest gravel content, 2nd-lowest mud content and 2nd-highest primary production values. In the Vlaming Sub-Basin, it coincides with middle- and inner-shelf seabed environments and is the 4th-most extensive seascape (Table 8.4). This seascape occurs in four discrete patches on the middle to inner shelf, south of Rottnest Island (Figure 8.8). This is the only seascape in the Vlaming Sub-Basin that occurs as more than three distinct areas, implying that the seabed environments that it represents are relatively fragmented than those represented by the other seascapes. Given that the individual patches are also relatively small suggests that the environments it represents are also uncommon for this basin.

Seascape 3 has a depth range of -185.69 to -197.98 m with a mean if -191.83 m (Figure 8.4). Nationally, it coincides with 47.69% reef and 31.72% plateau geomorphic features (Table 8.2). It is also characterised by the 2nd-highest gravel content and slope values. In the Vlaming Sub-Basin, this seascape coincides with middle-shelf environments and covers the 3rd-smallest area (Table 8.4). It is associated with seabed environments on the middle shelf and occurs as a very narrow strip, south of Rottnest Island, separating seascapes 4 and 8 (Figure 8.8). The restricted area and distribution of this seascape implies that the seabed environments it represents are relatively uncommon for this basin.

Seascape 4 has a depth range of -177.84 to -194.82 m with a mean if -186.33 m (Figure 8.4). Nationally, it coincides with 35.70% escarpments (Table 8.2). It is also characterised by the highest effective disturbance, 3rd-lowest mud content and seafloor temperatures, and 3rd-highest slope values. In the Vlaming Sub-Basin, this seascape coincides with outer- to inner-shelf environments and occurs as a continuous coast-parallel patch along its entire length (Figure 8.8) Seascape 4 covers the 2nd-largest area of the basin (Table 8.4). North of Rottnest Island, this seascape extends from the outer shelf right across to the inner shelf. This extended distribution, in the vicinity of the head of the Perth Canyon but not apparent anywhere else in the basin, implies that the shelf seabed environments it represents are similar across the shelf. Given that this cross-shelf extension occurs at the head of the Perth Canyon implies that the shelfal environments are being influenced by processes in the canyon. Cooler, nutrient-rich waters could be spilling onto the shelf from the canyon during upwelling periods and influencing the nature of the shelf environments as far as the inner shelf.



1. Shelf; knoll/abyssal-hills/hills/mountains/peak, tidal sandwave/sand bank; low mud; high primary production; cool; flat
2. Shelf; apron/fan; high effective disturbance; very gravelly; low mud; high primary production
3. Shelf; reef, plateau; gravelly; rugose
4. Shelf; escarpment; very high effective disturbance; low mud; cool; rugose
5. Shelf; escarpment; low gravel; muddy; cold
7. Shelf; apron/fan, ridge; low effective disturbance; low gravel; muddy; very low primary production
8. Shelf; ridge; high effective disturbance
11. Shelf; tidal sandwave/sand bank; very high primary production

Figure 8.8: *Map of the occurrence and distribution of on-shelf seascapes in the Vlaming Sub-Basin / Mentelle Basin region. The seascapes exhibit a general coast-parallel distribution that reflects the general trend of sediment facies.*

Seascape 6 has a depth range of -147.63 to -182.48 m with a mean if -165.05 m (Figure 8.4). Nationally, it coincides with 22.82% slope features (Table 8.2). It is also characterised by the 2nd-lowest effective disturbance and highest slope values. This seascape covers the 4th-smallest area and forms a semi-continuous patch along the outer shelf across the length of the basin (Figure 8.8; Table 8.4). The seabed environments represented by this seascape occur across the slope-shelf break and thus represent a transitional zone between the outer shelf environment represented by on-shelf seascape 4 and off-shelf seascape 3 (Figure 8.8). As such, the seabed environments this seascape represents mostly likely contain elements of both the on- and off-shelf seascapes, as derived for the Australian margin.

Seascape 7 has a depth range of -175.04 to -185.68 m with a mean if -180.36 m (Figure 8.4). Nationally, it coincides with 65.31% apron/fan and 50.23% ridge geomorphic features (Table 8.2). It is also characterised by the 3rd-lowest effective disturbance and gravel content, 2nd-highest mud content and lowest primary production values. This seascape covers the 2nd-smallest area in the Vlaming Sub-Basin and occurs as a discrete patch on the inner shelf west of Garden Island (Figure 8.8; Table 8.4). The relatively small and restricted distribution of this seascape implies that the seabed environments that it represents are relatively uncommon for this basin.

Seascape 8 has a depth range of -183.55 to -195.92 m with a mean if -189.74 m (Figure 8.4). Nationally, it coincides with 21.49% ridge features (Table 8.2). It is also characterised by the 2nd-highest effective disturbance. In the Vlaming Sub-Basin, this seascape coincides with middle- to inner-shelf environments. Seascape 8 covers the largest area in the Vlaming Sub-Basin and occurs as a contiguous coast-parallel patch along the entire basin length (Figure 8.8; Table 8.4). The extensive nature of this seascape implies that the seabed environments that it represents are common for this basin.

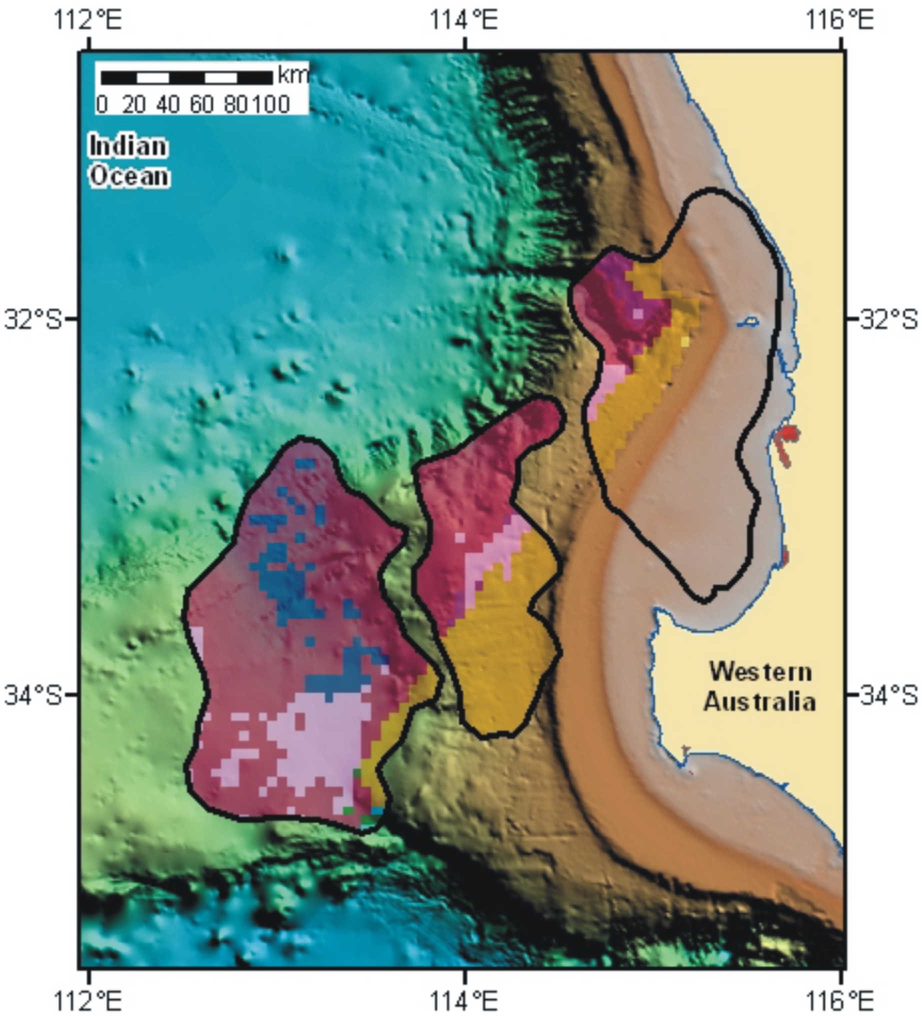
Seascape 11 has a depth range of -183.55 to -199.92 m with a mean if -198.57 m (Figure 8.4). Nationally, it coincides with 32.68% tidal-sandwave/sand bank features (Table 8.2). It is also characterised by the highest primary production values. Seascape 11 covers an area of 20 km^2 on the inner shelf between Garden and Rottnest Islands, which is the smallest area of all the seascapes in the basin (Figure 8.8; Table 8.4). The very restricted spatial distribution of this seascape implies that the seabed environments that this seascape represents are very rare for this basin.

8.3.2 Off-shelf Seascapes

In the Vlaming Sub-Basin / Mentelle Basin region, the dominant off-shelf seascapes (3, 8, 9) show a general margin-parallel distribution that is interspersed with the less dominant seascapes (1, 2, 4, 5, 6) (Figure 8.9). Seascape 7 is absent from the Vlaming Sub-Basin / Mentelle Basin region and except for seascapes 1 and 2, each of the other off-shelf seascapes mostly coincides with the Mentelle Basin.

Seascape 1 has a depth range of -1,544 to -6,285 m and a mean of -4,171 m which puts it in the abyssal zone of Australia's marine region (Vinogradova, 1997; Figure 8.5). Nationally, it coincides with 29.71% seamount/guyot, 27.18% apron/fan, 26.72% plateau, 26.69% deep/hole/valley, and 26.33% trench/trough geomorphic features (Table 8.2). It is also characterised by the lowest mud content and primary production values. Around the Australian margin, seascape 1 is principally associated with upper- to mid-slope environments in northern Australia, being extensive on the northwest and northeast margins (Figure 8.3). Seascape 1 is the 3rd- and 5th-most extensive seascape in the Vlaming Sub-Basin and Mentelle Basins, respectively (Table 8.4). In the Vlaming Sub-Basin it forms a relatively continuous patch that occurs on the northern flank of the Perth Canyon (Figure 8.9). In the Mentelle Basin it occurs as four small, isolated patches on the mid-slope. The occurrence of this seascape implies that the seabed environments it characterises, while being relatively uncommon for this region compared to the rest of the Australian margin, are more continuous in the Vlaming Sub-Basin than in the Mentelle Basin, where they are more fragmented.

Seascape 2 has a depth range -4,688 to -6,348 m and a mean of -5,964 m which puts it in the abyssal zone of Australia's marine region (Vinogradova, 1997; Figure 8.5). Nationally, it coincides with 80.70% reef and 48.05% apron/fan geomorphic features (Table 8.2). It is also characterised by the 3rd-highest gravel content, 2nd-lowest primary production values, highest sea floor temperatures, and lowest slope values. In the Vlaming Sub-Basin region, seascape 2 covers the smallest area, occupying only a 30 km^2 patch on the upper slope south of the Perth Canyon (Figure 8.9; Table 8.4). The fact that this seascape occurs as a small and isolated patch implies that the seabed environments represented by seascape 2 are extremely rare and anomalous compared to the rest of the Australian margin. Indeed, across the entire Australian margin, seascape 2 is principally associated with tropical margins, being most extensive on the shallow-gradient carbonate ramp of the North West Shelf and shallow water carbonate plateaus on the northeast margin (Figure 8.3).



1. Abyssal; seamount/guyot, apron/fan, plateau, deep/hole/valley, trench/trough; very low mud, very low primary production
2. Abyssal; reef, apron/fan; gravelly; low primary production; very warm, flat
3. Abyssal; terrace; high gravel; warm; rugose
4. Bathyal; abyssal plain/deep ocean floor; low mud, high primary production, cold
5. Abyssal; bank/shoal, escarpment, canyon, pinnacle; very gravelly, muddy; very high primary production; rugose
6. Bathyal; continental rise; abyssal plain/deep ocean floor, basin; low gravel; very muddy; cold; flat
8. Abyssal; trench/trough, plateau, deep/hole/valley; very low gravel; low primary production; warm; flat
9. Abyssal; canyon, seamount/guyot, basin, escarpment; low gravel; muddy; very rugose

Figure 8.9: *Map of the occurrence and distribution of off-shelf seascapes in the Vlaming Sub-Basin / Mentelle Basin region. The seascapes exhibit a general margin-parallel distribution and are dominated by seascape 9, which coincides with the steep, rugose sections of the mid- to upper-slope seabed environments.*

Seascape 3 has a depth range of -1,679 to -6,292 m with a mean of -4,956 m which puts it in the abyssal zone of Australia's marine region (Vinogradova, 1997; Figure 8.5). Nationally, this seascape coincides with 26.63% terrace geomorphic features (Table 8.2). It is also characterised by the 2nd-highest gravel content and sea floor temperatures, and 3rd-highest slope values. Interestingly, the distribution of this seascape around the Australian margin mostly coincides with regions of the margin that contain large offshore marginal plateaus and terraces, including in the Vlaming Sub-Basin / Mentelle Basin region (Figure 8.9). This implies that seascape 3 represents upper- to mid-slope environments where offshore features possibly preclude significant up-welling and reduce primary production in the surface waters. In the Vlaming Sub-Basin and Mentelle Basins seascape 3 covers the largest and 2nd-largest area, respectively (Table 8.4). It represents seabed environments that are generally above the elevation at which the submarine canyons head on this margin. In each basin seascape 3 forms contiguous patches meaning that the seabed environments it characterises are connected and continuous along this part of the Australian margin.

Seascape 4 has a depth range of -705 to -5,211 m with a mean of -1,763 m which puts it in the bathyal zone of Australia's marine region (Zezina, 1997; Figure 8.5). Nationally, this seascape coincides with 24.63% abyssal plain/deep ocean floor regions (Table 8.2). It is also characterised by the 3rd-lowest mud content, 2nd-highest primary production values, and 2nd-lowest sea floor temperatures. This seascape associated with the mid- to lower-slope and represents areas of the seabed characterised by coarser grain sizes compared to seascapes 6 and 7 that also represent these types of environments across the Australian margin. Seascape 4 covers the 2nd-smallest area in the Mentelle Basin region and is absent from the Vlaming Sub-Basin region (Table 8.4). In the Mentelle Basin it occurs as three very small and isolated patches on the southern margin of the Naturaliste Plateau (Figure 8.9). Because this seascape occurs as very small, isolated patches implies that the seabed environments it represents are very rare and fragmented for this region compared to the rest of the Australian margin.

Seascape 5 has a depth range of -910 to -6,133 m with a mean of -3,122 m which puts it in the abyssal zone (Vinogradova, 1997; Figure 8.5). Nationally, it coincides with 56.05% bank/shoal, 46.36% escarpment, 34.66% canyon and 30.24% pinnacle geomorphic features (Table 8.2). This seascape is also characterised by the highest gravel content, 2nd-lowest mud content, highest primary production values and 2nd-highest slope values. Seascape 5 also occurs on parts of the margin that are heavily dissected by submarine canyons. The very high primary production values are probably a result of up-welling of deep, cooler, nutrient-rich water from the adjacent abyssal plains. By contrast, dissected environments on the western margin of Australia north of the Vlaming Sub-Basin / Mentelle Basin region are characterised more by more moderate primary production values, and instead lead to the predominance of seascape 9 in these regions (Figure 8.9). This result possibly results from restricted up-welling to the surface of deep, nutrient-rich water by the presence of the shallow (<200 m) and southward-flowing Leeuwin Current. Seascape 5 occurs only in the Mentelle Basin region on the southern margin of the Naturaliste Plateau, and in association with seascape 4, where at 60 km^2 it covers the smallest area of all the seascapes in this basin (Table 8.4). The fact that it occurs only very sparsely within the region implies that the seabed environments associated with seascape 5 are extremely rare and isolated compared to the rest of the Australian margin.

Seascape 6 has a depth range of -390 to -3,391 m and a mean of -1,359 m which puts it in the bathyal zone of Australia's marine region (Zezina, 1997; Figure 8.5). Nationally, this seascape coincides with 45.93% continental rise, 35.82% abyssal plain/deep ocean floor, 33.12% basin geomorphic features (Table 8.2). It is also characterised by 3rd-lowest gravel content, highest mud content, 3rd-lowest sea floor temperatures, and second lowest slope values. Seascape 6 occurs only in the Mentelle Basin region and is the 4th-most extensive seascape (Table 8.4). In the Mentelle Basin it occurs as sparsely distributed patches on the sedimented, relatively flat Perth Abyssal Plain and saddle between the Naturaliste Plateau and continental margin (Figure 8.9). The relatively sparsely distributed nature of this seascape implies that the seabed environments it characterises are relatively fragmented and discontinuous despite some of the patches comprising relatively large areas.

Seascape 8 has a depth range of -2,579 to -6,323 m and a mean of -4,738 m which puts it in the abyssal zone of Australia's marine region (Vinogradova, 1997; Figure 8.5). Nationally, it coincides with 45.66% Trench/trough, 38.18% plateau and 29.21% deep/hole/valley geomorphic features (Table 8.2). It is also characterised by the lowest gravel content, 3rd-lowest primary production, 3rd highest sea floor temperatures, and 3rd-lowest slope values. In the Vlaming Sub-Basin and Mentelle Basins, seascape 8 covers the 2nd-smallest and the 3rd-largest area, respectively (Table 8.4). Around Australia, this seascape is associated with offshore marginal plateaus and terraces (Figure 8.3) and in the Vlaming Sub-Basin / Mentelle Basin region it occurs on the relatively low-gradient surfaces of the Naturaliste Plateau and adjoining saddle that connects it to the continental margin (Figure 8.9). Seabed environments represented by seascape 8 are relatively common across the Australian margin, and this is also the case for the Vlaming Sub-Basin / Mentelle Basin region. Its occurrence as relatively contiguous patches implies that the seabed environments it characterises are relatively connected, except on the distal surface of the Naturaliste Plateau, where the patches are small and fragmented.

Seascape 9 has a depth range of -457 to -6,058 m and a mean of -3,070 m which puts it in the abyssal zone of Australia's marine region (Vinogradova, 1997; Figure 8.5). Nationally, it coincides with 36.92% canyon, 33.95% seamount/guyot, 32.24% basin and 31.01% escarpment geomorphic features (Table 8.2). It is also characterised by the 2nd-lowest gravel content, 3rd-highest mud content, and highest slope values. Seascape 9 covers the 2nd-largest and largest areas in the Vlaming Sub-Basin and Mentelle Basins, respectively (Table 8.4). Seascape 9 coincides with mid- to upper-slope environments and submarine canyons on this margin (Figure 8.9). This seascape is associated with parts of the margin dissected by submarine canyons. Interestingly, in the Vlaming Sub-Basin, seascape 1 occurs on the steep northern flank of the Perth Canyon, but seascape 9 characterises similar environments on the southern flank and canyon floor. The Perth Canyon, which is the largest canyon on the Western Australian margin, is an ecological boundary and a known region of upwelling of cold, nutrient-rich water from the adjacent Perth Abyssal Plain (Figure 8.9). It is possible that this difference is represented by the distribution of seascapes 1 and 9, as defined by the physical properties used to derive them. Seabed environments associated with seascape 9 are relatively common across the Australian margin (Figure 8.7), and this is also the case for the Vlaming Sub-Basin / Mentelle Basin region. This implies that the seabed environments it represents are common and contiguous in this region.

Seascape 7 is the only seascape absent from the Vlaming Sub-Basin / Mentelle Basin region. Nationally, it has a depth range of -200 to -4,381 m with a mean of -1,425 m which puts it in the bathyal zone (Zezina, 1997; Figure 8.5). It coincides with 78.46% knoll/abyssal hills/hills/mountains/peak, 77.16% ridge and 25.16% abyssal plain/deep ocean floor geomorphic features (Table 8.2). It is also characterised by the 2nd-highest mud content, 3rd-highest primary production values, and lowest sea floor temperatures. Except for the Vlaming Sub-Basin / Mentelle Basin and SE Australian margin, the occurrence and distribution of seascape 7 is associated with the occurrence and distribution of seascape 6 (Figure 8.7). Generally, the deep sea environments that are represented by seascapes 6 and 7 are sinks for sediment transported down the slope and off the margin, as well as material that falls out of the water column.

8.4 FOCAL VARIETY

The focal variety analysis provides a spatial representation of habitat heterogeneity across the Australian margin. This procedure in ArcGIS simply counts up the number of different classes within a specified radius (in this case 50 km). Locations where seascapes and a range of geomorphic features intersect imply high potential habitat variability, and therefore high potential biotic variability (Day & Roff, 2000). Focal variety indices were thus calculated separately on the seascapes (which comprise continuous data) and geomorphic features (which comprise categorical spatial data; Figure 4.1) and the results combined. Areas of highest habitat heterogeneity are denoted by highest focal variety indices (i.e., where many different seascapes occur). Full details of the calculation of the focal variety index are presented in Whiteway et al. (2007).

In Australia, for the on-shelf region, greatest focal variety and thus seabed heterogeneity generally occurs on the outer shelf, as well as next to islands and coral reefs (Figure 8.10A). Generally, the shelf of northern Australia displays higher focal variety indices than those on the southern shelf regions. The inner-shelf, particularly in the Great Australian Bight, Gulf of Carpentaria and North West Shelf, displays low (<5) focal variety indices. This indicates that these places are characterised by relatively uniform seabed habitat types that cover relatively large areas. Highest (>12) focal variety indices occur at the southern end of the Great Barrier Reef-Capricorn Channel region, and on the Arafura and

Ashmore Shelves. These regions coincide with regions of the outer shelf that are relatively rugose (steep) and contain relatively complex geomorphology (i.e., a large number of different geomorphic features).

For the Vlaming-Mentelle region, the mid- to inner-shelf regions south of Rottnest Island shows up as an area of relatively high seabed habitat heterogeneity with focal variety indices of >11 (Figure 8.10B). This region is characterised by a relatively complex distribution of seascapes (Figure 8.8), re-emphasising the heterogeneous nature of this region of shelf.

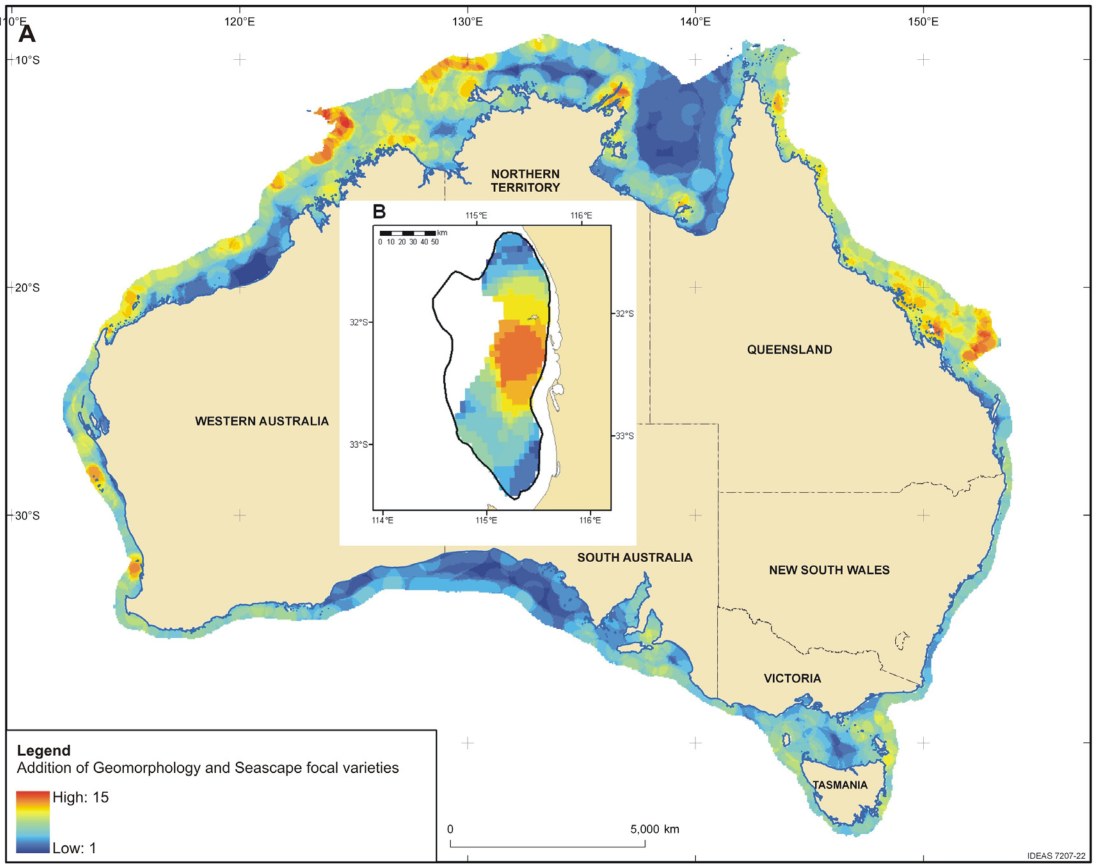


***Figure 8.10**: A) Focal variety indices for the on-shelf region of the Australian margin. The focal variety shows where the seabed is most heterogeneous. For the on-shelf region, greatest seabed heterogeneity (>12) occurs on the rugose and steep outer shelf regions, particularly at the southern end of the Great Barrier Reef-Capricorn Channel, and Arafura and Ashmore Shelves. B) Focal variety indices for the Vlaming Sub-Basin / Mentelle Basin region. Greatest focal variety occurs on the mid- to inner-shelf region south of Rottnest Island.*

For the off-shelf region, greatest focal variety occurs on the mid- to outer-slope regions, particularly associated with rugose regions of the slope dissected by submarine canyons and the margins of submerged marginal plateaus (Figure 8.11A). Highest (12-13) focal variety indices occur adjacent to Lord Howe Island, on the Kenn Plateau, near the head of the Townsville and Queensland Troughs and northwest margin of the Queensland Plateau, Offshore of the Sahul Banks, the southern margins of the Exmouth and Naturaliste Plateaus and Eyre Terrace, and the Diamantina Zone. Abyssal plain/deep ocean floor regions are characterised by relatively low (<3) focal variety indices implying that the seabed habitats in these environments are uniform and cover relatively large areas.

For the Vlaming-Mentelle region, the mid- to lower-slope coinciding with Mentelle Basin shows up as having the highest (>11) focal variety indices (Figure 8.11B). This region coincides with steep (rugose) slopes of several blind submarine canyons and relatively diverse seascapes. The mid- to upper-slope of the Vlaming Sub-Basin / Mentelle Basin region has relatively low focal variety indices (<6) associated with relatively less rugose slope environments. Although not the highest values, focal variety indices attain 8-10 over the Perth Canyon and reflect the relatively diverse nature of seabed environments associated with this large shelf intruding canyon, as shown by the concentration of seascape 1 with this feature (Figure 8.9).

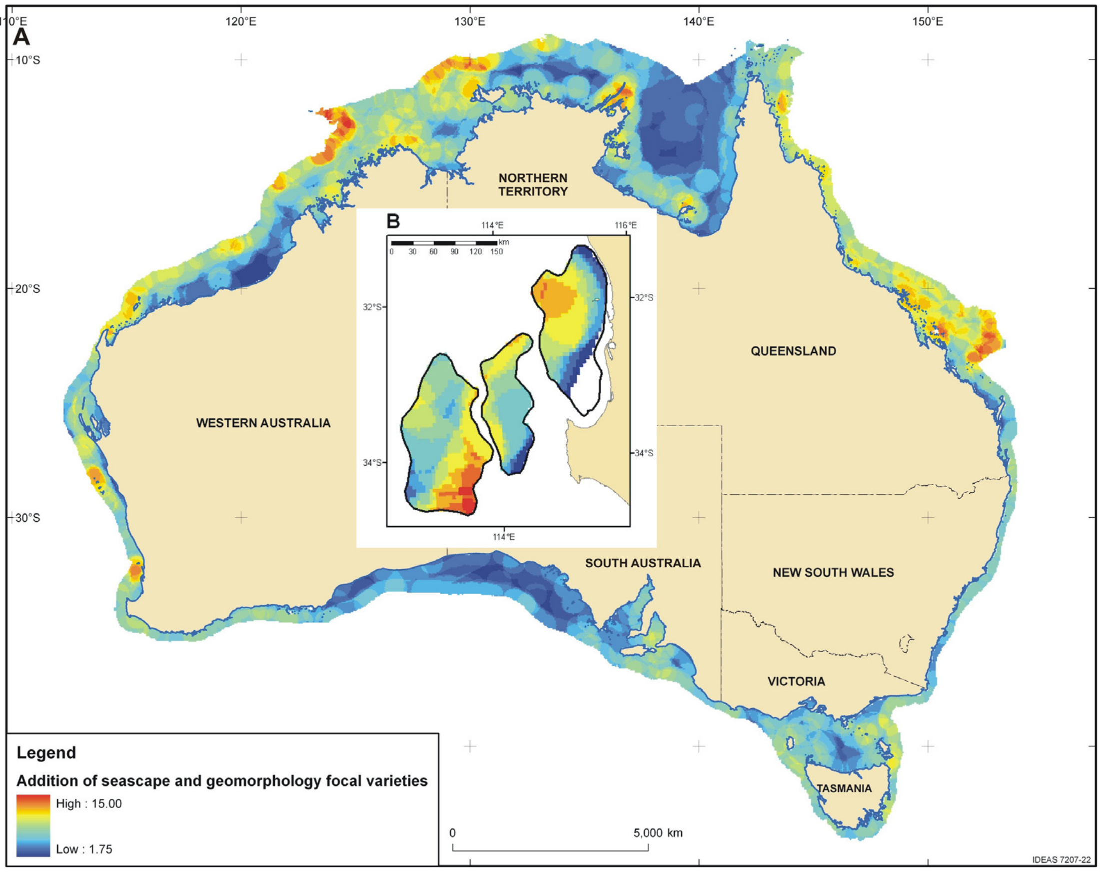


Figure 8.11: *A) Focal variety indices for the off-shelf region of the Australian margin. The focal variety shows where the seabed is most heterogeneous. For the off-shelf region, greatest seabed heterogeneity (>10) occurs on the mid- to lower-slope in regions characterised by rugose environments and areas incised by numerous submarine canyons. B) Focal variety indices for the Vlaming Sub-Basin / Mentelle Basin region. Greatest focal variety occurs on the mid- to lower*

slope coinciding with steep (rugose) slopes of blind canyons and relatively diverse seascapes.

8.5 DISCUSSION

The seascapes and focal variety analyses provide a method to highlight regions where biophysical parameters of the seabed are most diverse. Because the approach is consistent and quantitative at a national scale, it permits robust comparisons to be made between regions. The methods by which these datasets are derived are transparent (to all stakeholders), and is based on scientifically-valid methods and assumptions, thus improving its defensibility. As such, these approaches help reduce the level of uncertainty associated with mapping and characterising seabed habitats (and associated seabed biota), and thus help prevent the precautionary principle from being applied too liberally, which is of benefit to all stakeholders for Australia's marine environment.

Because seascapes and geomorphology are treated separately the focal variety analysis indicates that it is capturing real differences in seabed habitat heterogeneity at a broad-scale, and the magnitude and distribution of the indices are not solely based on underlying data density. This also implies that areas of diverse geomorphology are also areas of relatively diverse seabed habitat types, supporting the assumption that the spatial heterogeneity of the geomorphic features can be used as a first-order approximation of seabed habitat variability (i.e., the concept of physical surrogacy). This concept has particular application in the deep ocean where biological data are relatively scarce.

In the Vlaming Sub-Basin / Mentelle Basin region, rugose and dissected regions of the mid- to lower-slope show up as regions of greatest focal variety and seabed habitat heterogeneity. Areas of high seabed habitat heterogeneity have previously been prioritised and targeted as places for the establishment of marine protected areas. Targets for possible marine protected areas also include those that are unique (or relatively uncommon) and/or spatially restricted. In the Vlaming Sub-Basin / Mentelle Basin region these regions coincide with on-shelf seascapes 2, 3, 7 and 11 and off-shelf seascapes 1, 2, 4, 5, 6, and 8.

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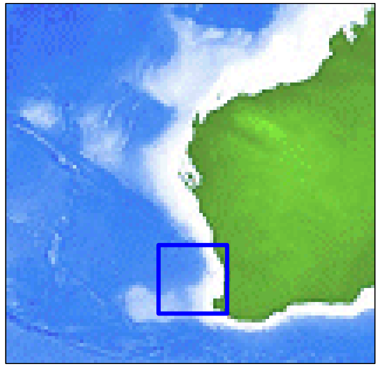
10. Appendix

10.1 ECOLOGY

Table 10.1: Pelagic species recorded from in and around Mentelle Basin and Vlamming Sub-basin. Species presented here were a) collected and identified by the Melbourne Museum from Southern Survey research surveys (SS01/1991, SS08/2005, and SS07/2005 & SS10/2005); b) listed in the Ocean Biogeographic Information System Δ (OBIS) for the search criteria latitude 35.0 S - 30.0 S and longitude 110.0 E - 115.0 E (depicted by the blue box on the adjacent Map). 'Mean depth' is the average of start and stop depths for gear that captured the specimen; 'latitude' and 'longitude' represent the location of the 1st specimen captured; 'occurrence' represents the number of different locations a species was collected from; 'total abundance' equals the total number of specimens captured within the region. Symbols: ■ = benthopelagic species, ^ = prized gamefish, * = commercially targeted or important species, † = minor commercial importance (bycatch, or low numbers).



Class	Group	Best Level of ID: Species… to group	Mean Depth (m)	Latitude	Longitude	Occurrence	Total Abundance
Cephalopoda	squid	*Abraliopsis gilchristi*	650	32 51 29 S	114 15 01 E	1	1
Cephalopoda	squid	*Enoploteuthis chunni*	390	32 02 18 S	114 54 30 E	2	15
Cephalopoda	squid	*Enoploteuthis sp*	390	32 00 48 S	114 55 00 E	2	4
Cephalopoda	squid	*Histioteuthis meleagroteuthis*	888.5	31 29 00 S	114 54 30 E	2	3
Cephalopoda	squid	*Histioteuthis miranda*	1115	31 32 35 S	114 56 24 E	4	4
Cephalopoda	squid	[Δ]*Liocranchia reinhardtia*	oceanic	-	-	-	-
Cephalopoda	squid	[Δ]*Lycoteuthis lorigera*	oceanic	-	-	-	-
Cephalopoda	squid	*Moroteuthis cf robsoni*	825	33 17 S	114 13 E	1	1
Cephalopoda	squid	[Δ]*Nototodarus gouldi* (Gould's flying squid)	oceanic	-	-	-	-
Cephalopoda	squid	*Ornithoteuthis volatilis* (Shiny bird	1050	33 17 S	114 13 E	1	1

		squid) †					
Cephalopoda	squid	*Spirula spirula* (Ram's Horn squid)	1295	32 57 12 S	114 35 00 E	1	1
Cephalopoda	squid	*Todarodes filippovae* (Arrow squid) *†	798.5	33 45 01 S	114 28 04 E	1	1
Cephalopoda	deep-sea squid	*Chiroteuthis sp*	655	34 15 00 S	114 20 00 E	1	1
Cephalopoda	deep-sea squid	*Lycoteuthis lorigera*	660	32 40 00 S	114 28 12 E	2	2
Cephalopoda	deep-sea squid	*Mastigoteuthis cordiformis*	976	32 38 48 S	114 26 24 E	1	1
Cephalopoda	deep-sea squid	*Teuthowenia pellucida*	929	31 21 24 S	114 56 36 E	1	1
Cephalopoda	deep-sea octopus	*Opisthoteuthis sp*	390	34 59 S	114 48 E	2	2
Elasmobranchii	shark	$^{\Delta}$*Alopias vulpinus* (Thresher Shark) *	0-550	-	-	-	-
Elasmobranchii	shark	$^{\Delta}$*Carcharhinus brachyurus* (Copper whaler) †	0-100	-	-	-	-
Elasmobranchii	shark	$^{\Delta}$*Carcharhinus falciformis* (Silky whaler shark)	oceanic	-	-	-	-
Elasmobranchii	shark	$^{\Delta}$*Carcharhinus longimanus* (Oceanic whitetip whaler)	0-230	-	-	-	-
Elasmobranchii	shark	$^{\Delta}$*Carcharhinus obscurus* (Dusky whaler) †	oceanic	-	-	-	-
Elasmobranchii	shark	$^{\Delta}$*Carcharodon carcharias* (Great white shark)	oceanic	-	-	-	-
Elasmobranchii	shark	$^{\Delta}$*Centrophorus moluccensis* (Smallfin gulper shark)	oceanic	-	-	-	-
Elasmobranchii	dog-shark	$^{\Delta}$*Centroscyllium kamoharai* (Bareskin dogfish)	730-1200	-	-	-	-

Elasmobranchii	dog-shark	Δ*Chiloscyllium punctatum* (Brownbanded bambooshark)	0-85■	-	-	-	-
Elasmobranchii	shark	Δ*Euprotomicrus bispinatus* (Pygmy shark)	0-1800	-	-	-	-
Elasmobranchii	shark	Δ*Galeocerdo cuvier* (Tiger shark)	1-371■	-	-	-	-
Elasmobranchii	shark	Δ*Galeorhinus galeus* (Hundshai)	0-1100■	-	-	-	-
Elasmobranchii	shark	Δ*Isistius brasiliensis* (Cookiecutter shark)	1-3700	-	-	-	-
Elasmobranchii	shark	Δ*Isurus oxyrinchus* (Atlantic mako)	oceanic	-	-	-	-
Elasmobranchii	shark	Δ*Lamna nasus* (Beaumaris shark)	0-715	-	-	-	-
Elasmobranchii	shark	Δ*Prionace glauca* (Blue shark)	oceanic	-	-	-	-
Elasmobranchii	shark	Δ*Pseudocarcharias kamoharai* (Crocodile shark)	0-590	-	-	-	-
Elasmobranchii	shark	Δ*Sphyrna lewini* (Bronze hammerhead shark)	0-512	-	-	-	-
Actinopterygii	tuna & macherel	Δ*Acanthocybium solandri* (Wahoo) **^**	oceanic	-	-	-	-
Actinopterygii	tuna & macherel	Δ<u>*Tetrapturus angustirostris*</u> (Shortbill spearfish) **^**	oceanic	-	-	-	-
Actinopterygii	tuna & macherel	Δ<u>*Tetrapturus audax*</u> (Striped marlin) **^**	oceanic	-	-	-	-
Actinopterygii	tuna & macherel	Δ<u>*Thunnus alalunga*</u> (Albacore) **^**	oceanic	-	-	-	-
Actinopterygii	tuna & macherel	Δ<u>*Thunnus albacares*</u> (Allison's tuna) **^**	oceanic	-	-	-	-

Actinopterygii	tuna & macherel	Δ*Thunnus maccoyii* (Southern bluefin tuna) *^	oceanic	-	-	-	-
Actinopterygii	tuna & macherel	Δ*Makaira indica* (Black marlin) ^	oceanic	-	-	-	-
Actinopterygii	tuna & macherel	Δ*Makaira nigricans* (Atlantic blue marlin) ^	oceanic	-	-	-	-
Actinopterygii	tuna & macherel	Δ*Thunnus obesus* (Bigeye tuna) *^	oceanic	-	-	-	-
Actinopterygii	tuna & macherel	Δ*Katsuwonus pelamis* (Oceanic bonito)	oceanic	-	-	-	-
Actinopterygii	fish	Δ*Argyropelecus gigas* (Giant hatchetfish)	300-650	-	-	-	-
Actinopterygii	fish	Δ*Bathygadus spongiceps* (a Grenadier)	1207-1463	-	-	-	-
Actinopterygii	fish	Δ*Beryx splendens* (Splendid alfonsino)	25-1300■	-	-	-	-
Actinopterygii	fish	Δ*Brama brama* (Atlantic pomfret)	0-1000	-	-	-	-
Actinopterygii	fish	Δ*Centroberyx affinis* (Redfish)	10-450■	-	-	-	-
Actinopterygii	fish	Δ*Centroberyx gerrardi* (Bight redfish)	10-500	-	-	-	-
Actinopterygii	fish	Δ*Centrobranchus nigroocellatus* (Pig-headed lanternfish)	0 – 700	-	-	-	-
Actinopterygii	fish	Δ*Centrolophus niger* (Blackfish)	40-1050	-	-	-	-
Actinopterygii	fish	Δ*Ceratoscopelus warmingii* (Lanternfish)	0 – 2014	-	-	-	-
Actinopterygii	fish	Δ*Chauliodus sloani* (Needletooth)	473-2800	-	-	-	-

Actinopterygii	fish	Δ*Coryphaena hippurus* (Common dolphinfish)	0-85	-	-	-	-
Actinopterygii	fish	Δ*Dannevigia tusca* (Australian tusk)	115-400■	-	-	-	-
Actinopterygii	fish	Δ*Diaphus meadi* (Mead's lanternfish)	? – 250	-	-	-	-
Actinopterygii	fish	Δ*Diaphus mollis* (Lanternfish)	50 – 600	-	-	-	-
Actinopterygii	fish	Δ*Diaphus watasei*	100 – 550■	-	-	-	-
Actinopterygii	fish	Δ*Diodon holocanthus* (Long-spine porcupinefish)	2 – 200■	-	-	-	-
Actinopterygii	fish	Δ*Diogenichthys atlanticus* (Lanternfish)	18 – 1050	-	-	-	-
Actinopterygii	fish	Δ*Gasterochisma melampus* (Butterfly kingfish)	200-?	-	-	-	-
Actinopterygii	fish	Δ*Gephyroberyx darwinii* (Darwin's slimehead)	9 – 1210■	-	-	-	-
Actinopterygii	fish	Δ*Gonichthys cocco* (Lanternfish)	0 – 1000	-	-	-	-
Actinopterygii	fish	Δ*Gonichthys cocco(as Gonichthys coccoi)* (Lanternfish)		-	-	-	-
Actinopterygii	fish	Δ*Hoplostethus atlanticus* (Orange roughy)	180-1809	-	-	-	-
Actinopterygii	fish	Δ*Hygophum hanseni*	57 – 728	-	-	-	-
Actinopterygii	fish	Δ*Hygophum hygomii* (Lanternfish)	0 – 800	-	-	-	-
Actinopterygii	fish	Δ*Hyperoglyphe antarctica* (Deepsea trevalla)	40-1500■	-	-	-	-
Actinopterygii	fish	Δ*Istiophorus platypterus* (Indo-Pacific sailfish) **^**	0 – 200	-	-	-	-
Actinopterygii	fish	Δ*Lampanyctus alatus*	40 – 1500	-	-	-	-
Actinopterygii	fish	Δ*Lobianchia gemellari*	25 – 800	-	-	-	-

Actinopterygii	fish	△*Mola mola* (Ocean sunfish)	30-480	-	-	-	-
Actinopterygii	fish	△*Mora moro* (Common mora)	450-2500	-	-	-	-
Actinopterygii	fish	△*Myctophum asperum* (Prickly lanternfish)	0 – 750	-	-	-	-
Actinopterygii	fish	△*Myctophum nitidulum* (Lantern fish)	0 – 950	-	-	-	-
Actinopterygii	fish	△*Myctophum phengodes*	Deepwater	-	-	-	-
Actinopterygii	fish	△*Narcetes lloydi*	920 – 1050	-	-	-	-
Actinopterygii	fish	△*Nemadactylus macropterus* (Tarakihi)	22-450	-	-	-	-
Actinopterygii	fish	△*Nemadactylus valenciennesi* (Sea carp)	40-240	-	-	-	-
Actinopterygii	fish	△*Neosebastes nigropunctatus* (Black-spotted gurnard-perch)	30 – 556■	-	-	-	-
Actinopterygii	fish	△*Pentapodus vitta* (Striped whiptail)	■	-	-	-	-
Actinopterygii	fish	△*Pseudopentaceros richardsoni* (Pelagic armorhead)	0 – 600	-	-	-	-
Actinopterygii	fish	△*Pyramodon punctatus* (Dogtooth pearlfish or cuskeel)	120 – 731■	-	-	-	-
Actinopterygii	fish	△*Rouleina guentheri* (a smoothhead)	500 – 1300	-	-	-	-
Actinopterygii	fish	△*Ruvettus pretiosus* (Oilfish snake-mackerel)	100 – 800■	-	-	-	-
Actinopterygii	fish	△*Sarda australis* (Australian bonito) **^**		-	-	-	-
Actinopterygii	fish	△*Scombrolabrax heterolepis* (Longfin escolar)	100 – 900■	-	-	-	-
Actinopterygii	fish	△*Scorpis lineolata* (Silver sweep)	? – 30■	-	-	-	-

Actinopterygii	fish	∆*Seriola lalandi* (Yellowtail amberjack)	3-825■	-	-	-	-
Actinopterygii	fish	∆*Seriolella brama* (Common warehou)	22-400■	-	-	-	-
Actinopterygii	fish	∆*Squalogadus modificatus* (a grenadier)	600 – 1400	-	-	-	-
Actinopterygii	fish	*Sternoptyx diaphana* (Diaphanous hatchetfish)	400 – 3676	-	-	-	-
Actinopterygii	fish	*Sternoptyx obscura* (a hatchetfish)	500 – 1000	-	-	-	-
Actinopterygii	fish	*Trichiurus lepturus* (Atlantic cutlassfish)	0 – 400■	-	-	-	-
Actinopterygii	fish	*Vinciguerria attenuata* (Lightfish)	100 – 600	-	-	-	-
Actinopterygii	fish	*Vinciguerria nimbaria* (Frilled lighthouse fish)	20 – 5000	-	-	-	-
Actinopterygii	fish	*Xiphias gladius* (Broadbill)	0-800	-	-	-	-

Table 10.2: Demersal and bathydemersal species recorded in and around Mentelle Basin and Vlamming Sub-basin. Species presented here were a) collected and identified by the Melbourne Museum from Southern Survey research surveys (SS01/1991, SS08/2005, and SS07/2005 & SS10/2005), and b) listed in the Ocean Biogeographic Information System Δ (OBIS) for the search criteria latitude 35.0 S - 30.0 S and longitude 110.0 E - 115.0 E (depicted by the blue box on the adjacent Map). Definitions of terms are listed in Table 10.1, ++= found in polluted or organically rich sediments. A full species list of demersal fishes and their capture details from west coast shelf and slope habitats can be found in Williams et al., (1996).

Class	Group	Best Level of ID: Species… to group	Depth (m)	Latitude	Longitude	Occurrence	Total Abundance
Bivalvia	bivalve	Bivalvia	1440	32 51 16 S	114 15 25 E	1	1
Cephalopoda	deep-sea octopus	*Benthoctopus* sp	825	34 58 S	114 51 E	1	1
Cephalopoda	octopus	Δ*Eledone palari* (Horned octopus)	to 500	-	-	-	-
Cephalopoda	squid	*Rossia australis* (big bottom bobtail squid)	450	34 15 00 S	114 20 00 E	1	1
Cephalopoda	squid	*Rossia* sp.	390	31 20 30 S	114 53 36 E	2	4
Cephalopoda	cuttlefish	*Sepia chirotrema*	210	33 49 42 S	114 17 30 E	2	3
Cephalopoda	cuttlefish	*Sepia cottoni*	210	33 49 42 S	114 17 30 E	1	1
Cephalopoda	cuttlefish	*Sepia cultrate* (knife-bone cuttlefish)	370	32 57 12 S	114 35 00 E	4	14
Malacostraca	isopod	*Bathynomus* sp	614	33 25 30 S	114 21 00 E	1	1
Malacostraca	crab	*Dagnaudus petterdi*	457	31 44 08 S	114 47 35 E	2	4
Malacostraca	crab	*Ebalia tuberculosa*	431	31 44 08 S	114 47 35 E	4	25
Malacostraca	crab	*Homologenus braueri*	987	33 00 30 S	114 34 16 E	1	1
Malacostraca	crab	*Mathildella serrata*	687	31 00 17 S	114 49 23 E	1	2
Malacostraca	crab	*Mursia* sp	410	31 16 12 S	114 50 12 E	1	1
Malacostraca	crab	*Psopheticus stridulans* (squeaker crab)	410	33 00 35 S	114 34 12 E	1	2
Malacostraca	crab	*Rochinia* sp (spiny crab)	404	32 59 37 S	114 34 55 E	2	2
Malacostraca	crab	*Sympagurus dimorphus*	410	34 00 39 S	114 26 35 E	1	2
Malacostraca	crab	*Trichopeltarion* sp	404	34 00 57 S	114 26 28 E	3	26
Malacostraca	crab	*Tymolus brucei*	479	33 00 30 S	114 34 16 E	1	7
Malacostraca	crab	*Tymolus similis*	461	33 00 07 S	114 34 30 E	6	117
Malacostraca	crab	*Umalia trirufomaculata*	987	31 43 37 S	114 45 36 E	1	2
Malacostraca	spider crab	*Cyrtomaia maccullochi* (slender-handed spider crab)	442	31 43 37 S	114 45 36 E	3	4

Malacostraca	spider crab	*Dorhynchus amusculus*	479	31 43 37 S	114 45 36 E	1	1
Malacostraca	spider crab	*Griffinia lappacea*	479	34 00 39 S	114 26 35 E	1	1
Malacostraca	spider crab	*Physachaeus ctenurus*	461	34 00 57 S	114 26 28 E	5	27
Malacostraca	spider crab	*Platymaia wyvillethompsoni* (3-spined spider crab)	410	34 00 39 S	114 26 35 E	1	1
Malacostraca	hermit crab	*Oncopagurus indicus*	418	31 16 48 S	114 50 18 E	1	1
Malacostraca	hermit crab	*Oncopagurus monstrosus*	442	33 00 35 S	114 34 12 E	4	9
Malacostraca	hermit crab	*Paguristes aciculus*	442	32 59 37 S	114 34 55 E	7	86
Malacostraca	hermit crab	*Paragiopagurus* sp	410	34 00 39 S	114 26 35 E	1	3
Malacostraca	hermit crab	*Propagurus haigae*	404	34 00 57 S	114 26 28 E	3	6
Malacostraca	parasitic isopod	*Bopyrid* sp	417.5	33 24 36 S	114 22 30 E	2	2
Malacostraca	ghost shrimp	*Ambiaxius* sp	410	34 56 54 S	114 29 18 E	1	2
Malacostraca	ghost shrimp	*Axiid* sp	410	34 57 18 S	114 29 00 E	1	1
Malacostraca	caridean shrimp	*Aegaeon lacazei*	394	32 18 18 S	114 29 00 E	1	2
Malacostraca	caridean shrimp	*Lissosabinea cf tridentata*	418	31 00 45 S	114 49 30 E	1	1
Malacostraca	caridean shrimp	*Plesionika orientalis* (golden prawn)	521	34 00 57 S	114 26 28 E	1	15
Malacostraca	penaeid prawn	*Hadropenaeus lucasii* (Trident shrimp)	461	34 00 57 S	114 26 28 E	5	30
Malacostraca	penaeid prawn	*Metapenaeopsis* sp	394	33 00 35 S	114 34 12 E	1	2
Malacostraca	scampi	*Metanephrops boschmai* (Bight lobster) *****	404	33 00 35 S	114 34 12 E	3	11
Malacostraca	scampi	*Metanephrops velutinus* (Velvet lobster) *****	418	32 59 37 S	114 34 55 E	3	7
Malacostraca	slipper lobster	*Ibacus alticrenatus* (Balmain Bug) *****	442	33 00 07 S	114 34 30 E	6	32
Malacostraca	slipper lobster	*Polycheles auriculatus*	987	34 00 39 S	114 26 35 E	1	1
Malacostraca	squat lobster	*Munida* sp	418	32 59 37 S	114 34 55 E	1	1
Malacostraca	squat lobster	*Uroptychus australis*	987	31 44 08 S	114 47 35 E	1	1
Malacostraca	squat lobster	*Uroptychus gracilimanus*	418	33 00 30 S	114 34 16 E	2	10
Maxillipoda	parasitic barnacle	*Rhizocephala* sp	394	33 00 07 S	114 34 30 E	1	1
Polychaeta	tubeworms	Ampharetidae - deposit feeders	990	33 00 30 S	114 34 16 E	7	8
Polychaeta	fireworms	Amphinomidae (fireworms) – carnivorous reef dwellers	1550	33 00 07 S	114 34 30 E	3	3
Polychaeta	burrowers	Capitellidae (lugworms)- burrowers ++	1635	31 40 48 S	114 50 38 E	2	2
Polychaeta	burrowers	Cirratulidae (Spaghetti worms) – deposit feeders	990	31 41 06 S	114 50 46 E	8	14

Polychaeta	tubeworms	Fauveliopsidae – deep sea deposit feeders	1340	33 00 30 S	114 34 16 E	2	2
Polychaeta	burrowers	Glyceridae (Blood worms) – predaceous carnivores	1440	33 00 07 S	114 34 30 E	1	1
Polychaeta	tubicolous	Goniadidae - carnivorous	990	33 00 30 S	114 34 16 E	8	10
Polychaeta	burrowers	Lumbrineridae - predaceous carnivores or scavengers	1090	33 00 07 S	114 34 30 E	8	10
Polychaeta	burrowers/borers	Lysidice sp - omnivores and detritivores	418	31 00 45 S	114 49 30 E	1	1
Polychaeta	burrowers	Nephtyidae – carnivorous/omnivorous	1090	31 00 17 S	114 49 23 E	2	2
Polychaeta	tubicolous	Onuphidae - omnivorous scavengers	1605	33 00 30 S	114 34 16 E	3	3
Polychaeta	burrowers	Orbiniidae (seepworms) - deposit feeders	1030	33 00 35 S	114 34 12 E	3	3
Polychaeta	burrowers	Opheliidae (fusiform worms)	1550	33 00 07 S	114 34 30 E	4	6
Polychaeta	burrowers	Paraonidae (corkscrew worms)	1090	32 59 37 S	114 34 55 E	8	12
Polychaeta	tubeworms/burrowers	Scalibregmatidae - deposit feeders	1090	33 00 07 S	114 34 30 E	3	3
Polychaeta	tubeworms	Poecilochaetida (U-shaped tubeworms)	1470	33 00 30 S	114 34 16 E	2	3
Polychaeta	tubeworms	Serpulidae (calcareous tubeworms)	1660	34 00 39 S	114 26 35 E	1	1
Polychaeta	tubeworms	Siboglinidae (bearded tubeworms)	1550	34 00 57 S	114 26 28 E	3	7
Polychaeta	tubeworms/burrowers	Sigalionidae (scale worms) – burrowing predators	1440	33 00 30 S	114 34 16 E	1	1
Polychaeta	burrowers/borers	Spionidae (palp worms) - suspension and deposit feeders	990	33 00 07 S	114 34 30 E	12	45
Polychaeta	burrowers	Syllidae (ragworms) - predaceous carnivores	1090	33 00 35 S	114 34 12 E	2	2
Polychaeta	tubeworms	Terebellidae (spaghetti worms) – deposit feeders	1440	32 59 37 S	114 34 55 E	1	1
Polychaeta	tubicolous	Trichobranchidae (pom-pom gill worms) - deposit feeders	1470	34 01 04 S	114 26 24 E	2	2
Scaphopoda	tusk shells	Scaphopoda	1075	34 01 11 S	114 26 20 E	4	4
Ophiuroids	brittlestar	*Amphiura* sp (MoV 3579)	-	-	-	2	-
Ophiuroids	brittlestar	*Amphiura* sp (MoV 5508)	-	-	-	1	-
Ophiuroids	brittlestar	*Amphiura* sp (MoV 5519)	-	-	-	2	-
Ophiuroids	brittlestar	*Amphilimna transacta*	-	-	-	2	-
Ophiuroids	brittlestar	*Ophiocymbium*	-	-	-	1	-
Ophiuroids	brittlestar	*Ophiomyces delata*	-	-	-	1	-
Ophiuroids	brittlestar	*Ophiotoma* sp (MoV 5504)	-	-	-	1	-

Ophiuroids	brittlestar	*Ophiopsammus assimilis*	-	-	-	1	-
Ophiuroids	brittlestar	*Ophiomyxa* sp (MoV 5487)	-	-	-	2	-
Ophiuroids	brittlestar	*Ophioscolex* sp (MoV 2721)	-	-	-	4	-
Ophiuroids	brittlestar	*Amphiophiura urbana*	-	-	-	2	-
Ophiuroids	brittlestar	*Ophiomastus tegulitius*	-	-	-	1	-
Ophiuroids	brittlestar	*Ophiomusium anisacanthum*	-	-	-	3	-
Ophiuroids	brittlestar	*Ophiomusium relictum*	-	-	-	3	-
Ophiuroids	brittlestar	*Ophiura ooplax*	-	-	-	4	-
Ophiuroids	brittlestar	*Ophiura palliate*	-	-	-	2	-
Ophiuroids	brittlestar	*Ophiura* sp (Mov 2734)	-	-	-	1	-
Holothuroidea	sea cucumber	*Laetmogone cf theeli*	987	33 45 12 S	114 28 36 E	1	3
Holothuroidea	sea cucumber	*Mesothuria holothurioides*	987	31 20 30 S	114 53 36 E	1	2
Holothuroidea	sea cucumber	*Pseudostichopus cf spiculiferus*	498	31 20 30 S	114 53 36 E	2	4
Holothuroidea	sea cucumber	*Pseudostichopus hyalegerus*	418	32 19 48 S	114 28 36 E	1	1
Elasmobranchii	shark	[Δ]*Asymbolus funebris* (Blotched Catshark) †	144	-	-	-	-
Elasmobranchii	shark	[Δ]*Asymbolus occiduus* (Western spotted catshark) †	98-400	-	-	-	-
Elasmobranchii	dog-shark	[Δ]*Centroscymnus crepidater* (Longnose velvet dogfish)	230-1500	-	-	-	-
Elasmobranchii	dog-shark	[Δ]*Centroscymnus owstoni* (Roughskin dogfish)	100-1500	-	-	-	-
Elasmobranchii	shark	[Δ]*Etmopterus lucifer* (Blackbelly lanternshark)	15-1250	-	-	-	-
Elasmobranchii	shark	[Δ]*Etmopterus pusillus* (Smooth lanternshark)	0-1070	-	-	-	-
Elasmobranchii	shark	[Δ]*Heptranchias perlo* (Sharpnose sevengill shark)	0-1000	-	-	-	-
Elasmobranchii	shark	[Δ]*Heterodontus portusjacksoni* (Port Jackson shark)	0-275	-	-	-	-
Elasmobranchii	shark	[Δ]*Mustelus antarcticus* (Gummy shark)	0-350	-	-	-	-
Elasmobranchii	rays and skate	[Δ]*Myliobatis australis* (Eagle ray)	nearshore	-	-	-	-

Elasmobranchii	shark	Δ*Notorynchus cepedianus* (Broadnose sevengill shark)	0-570	-	-	-	-
Elasmobranchii	rays and skate	Δ*Pavoraja alleni* (Allens skate)	200-460	-	-	-	-
Elasmobranchii	shark	Δ*Squatina tergocellata* (Ornate angelshark)	128-400	-	-	-	-
Elasmobranchii	chimarea	Δ*Callorhinchus milii* (Elephant fish) *	0-227	-	-	-	-
Actinopterygii	fish	Δ*Acanthistius serratus* (Western wirrah) †	inshore	-	-	-	-
Actinopterygii	fish	Δ*Aldrovandia affinis* (Gilbert's halosaurid fish)	730-2560	-	-	-	-
Actinopterygii	fish	Δ*Alepocephalus antipodianus*	430-1160	-	-	-	-
Actinopterygii	fish	Δ*Aphareus rutilans* (Rusty jobfish)	100-330	-	-	-	-
Actinopterygii	fish	Δ*Apogonops anomalus* (Three-spined cardinalfish)	0-600	-	-	-	-
Actinopterygii	fish	Δ*Argyrosomus hololepidotus* (Mulloway)	inshore	-	-	-	-
Actinopterygii	fish	Δ*Caelorinchus maurofasciatus* (Dark banded rattail)	Deepwater	-	-	-	-
Actinopterygii	fish	Δ*Chelidonichthys kumu* (Bluefin gurnard)	1-200	-	-	-	-
Actinopterygii	fish	Δ*Cyttus traversi* (King dory)	200-800	-	-	-	-
Actinopterygii	fish	Δ*Epigonus robustus* (Robust cardinalfish)	500-3000	-	-	-	-
Actinopterygii	fish	Δ*Epinephelus radiatus* (Oblique-banded grouper)	18-383	-	-	-	-
Actinopterygii	fish	Δ*Helicolenus percoides* (Coral cod)	50-750	-	-	-	-
Actinopterygii	fish	Δ*Hymenocephalus nascens*	366-855	-	-	-	-
Actinopterygii	fish	Δ*Istiblennius lineatus* (Lined rockskipper)	0-3	-	-	-	-
Actinopterygii	fish	Δ*Kathetostoma nigrofasciatum* (Deepwater stargazer)	130-270	-	-	-	-
Actinopterygii	fish	Δ*Lepidoperca pulchella* (Orange perch)	50-400	-	-	-	-
Actinopterygii	fish	Δ*Lepidopus caudatus* (Scabbard fish)	42-620	-	-	-	-
Actinopterygii	fish	Δ*Neocyttus rhomboidalis* (Spikey oreo)	200-1240	-	-	-	-
Actinopterygii	fish	Δ*Nezumia soela*	830-1500	-	-	-	-
Actinopterygii	fish	Δ*Nezumia wularnia*	500-1320	-	-	-	-
Actinopterygii	fish	Δ*Oplegnathus woodwardi* (Knifejaw)	50-400	-	-	-	-
Actinopterygii	fish	Δ*Plagiogeneion macrolepis* (Rubyfish)	95-390	-	-	-	-

Actinopterygii	fish	ΔPlatycephalus conatus (Deepwater flathead)	70-490	-	-	-	-
Actinopterygii	fish	ΔPagrus auratus (Pink Snapper) *	0-200	-	-	-	-
Actinopterygii	fish	ΔPlectranthias alleni	62-56	-	-	-	-
Actinopterygii	fish	ΔPseudocyttus maculatus (Smooth dory)	400-1500	-	-	-	-
Actinopterygii	fish	ΔPterygotrigla polyommata (Flying gurnard)	35-400	-	-	-	-
Actinopterygii	fish	ΔRexea solandri (Silver gemfish)	100-800	-	-	-	-
Actinopterygii	fish	ΔScartelaos histophorus (Walking goby)		-	-	-	-
Actinopterygii	fish	ΔSetarches guntheri	150-732	-	-	-	-
Actinopterygii	fish	ΔSqualus megalops (Shortnose spurdog)	30-750	-	-	-	-
Actinopterygii	fish	ΔSqualus mitsukurii (Shortspine spurdog)	0-950	-	-	-	-
Actinopterygii	fish	ΔSynagrops japonicus (Japanese splitfin)	100-800	-	-	-	-
Actinopterygii	fish	ΔSynagrops philippinensis	186-220	-	-	-	-
Actinopterygii	fish	ΔTrachinops brauni (a hulafish)	coastal	-	-	-	-
Actinopterygii	fish	ΔZenopsis nebulosus (Mirror dory)	30-800	-	-	-	-
Actinopterygii	fish	ΔZenopsis nebulosus (Mirror dory)	30-800	-	-	-	-

10.2 SEDIMENTS SAMPLES

10.2.1 Vlaming Sub-Basin Sediment Samples

A total of 112 sediment samples were extracted from the MARS database for the Vlaming Sub-basin. This included both surface and down core samples. There were 81 surface sediment samples (Table 10.3) and 31 down core samples. Of the surface samples, five gravity cores taken in the area, 24 samples were collected by dredge (2 benthic, 5 pipe and 17 unspecified) and 52 by grab sampler (7 Smith Macintyre and 45 Van Veen). The samples were collected from five individual surveys to the area (Table 10.4).

The average grainsize for the surface samples is 25.5% mud (range, 0.02 – 93.62%, SD 37.65), 64% sand (range, 6.38 – 99.82%, SD 35.4) and 10.5% gravel (range, 0 -89.16%, SD 18.67). The samples are spatially variable. Sandier samples are located on the shallower depths (less than 200 m) and muddier samples are located at greater depths (greater than 200 m). Gravels are located at depths shallower than 200m.

There were 80 surface samples analysed for carbonate content (Table 10.3). The samples are carbonate rich with average bulk carbonate content of 78.5%. There were 31 down core samples analysed. The average bulk carbonate content is 82.6%.

Table 10.3: Vlaming Sub-basin surface sediment grainsize samples from MARS database.

Survey Id	Sample Id	Sample No	Sample Type	Latitude	Longitude	Mud %	Sand %	Gravel %
FR 01/96	FR01/96DR 1	1746217	DREDGE PIPE	-31.75000	115.40017	0.03	98.91	1.06
FR 01/96	FR01/96DR 2	1746218	DREDGE PIPE	-31.75250	115.26617	0.23	83.23	16.54
FR 01/96	FR01/96DR 3	1746219	DREDGE PIPE	-31.75583	115.15650	0.60	91.76	7.64
FR 01/96	FR01/96DR 4	1746220	DREDGE PIPE	-31.47700	115.43450	0.06	96.24	3.70
FR 01/96	FR01/96DR 6	1746221	DREDGE PIPE	-31.59533	115.21350	0.05	74.05	25.89
FR 01/96	FR01/96DR 7	1746222	DREDGE BENTHIC	-31.64500	115.13083	1.21	92.51	6.28
FR 01/96	FR01/96DR 8	1746223	DREDGE BENTHIC	-31.69733	115.05083	0.61	96.19	3.20
SS08/2005	SS082005 01GR02	1682918	GRAB SMITH MCINTYRE	-32.04547	115.44532	0.07	98.98	0.95
SS08/2005	SS082005/ 01GR03	1682919	GRAB SMITH MCINTYRE	-32.04532	115.44532	0.03	99.41	0.56
SS08/2005	SS082005 02GC23 0-2cm	1694985	CORE GRAVITY	-32.05150	114.64853	91.91	8.09	0.00
SS08/2005	SS082005 02GC24 0-2cm	1694986	CORE GRAVITY	-32.04295	114.65833	93.62	6.38	0.00
SS08/2005	SS082005 26GC21 0-2cm	1695000	CORE GRAVITY	-31.97215	114.60263	87.46	12.54	0.00
SS08/2005	SS082005 28GC22	1695002	CORE GRAVITY	-32.06507	114.66807	86.84	13.16	0.00

Survey Id	Sample Id 0-2cm	Sample No	Sample Type	Latitude	Longitude	Mud %	Sand %	Gravel %
SS 07/2005	296/34GR35	1680496	GRAB SMITH MCINTYRE	-31.69710	114.87808	68.54	31.41	0.06
SS 07/2005	296/35GR36	1680497	GRAB SMITH MCINTYRE	-31.72708	114.75668	54.80	44.83	0.38
SS 07/2005	296/50GR51	1680512	GRAB SMITH MCINTYRE	-31.85337	115.02158	28.91	70.09	1.00
SS 07/2005	296/31GR32A	1680528	GRAB SMITH MCINTYRE	-31.61193	115.17823	0.06	92.13	7.81
SS 07/2005	296/32GR33A	1680530	GRAB SMITH MCINTYRE	-31.65435	115.02378	0.69	90.66	8.65
Postglacial	U172006	1599944	GRAB VAN VEEN	-33.22500	115.30833	0.03	99.82	0.15
Postglacial	U172027	1599960	GRAB VAN VEEN	-33.30000	115.11667	0.28	40.99	58.73
Postglacial	U172042	1599975	GRAB VAN VEEN	-33.37500	115.25833	0.04	74.54	25.42
Postglacial	U172043	1599976	GRAB VAN VEEN	-33.33333	115.27500	0.08	88.15	11.77
Postglacial	U172044	1599977	GRAB VAN VEEN	-33.28333	115.30000	0.04	98.20	1.77
Postglacial	U172045	1599978	GRAB VAN VEEN	-33.30833	115.35833	0.08	79.36	20.56
Postglacial	U172046	1599979	GRAB VAN VEEN	-33.31667	115.41667	0.19	94.47	5.34
Postglacial	U172056	1599989	GRAB VAN VEEN	-33.05000	115.31667	0.09	92.07	7.84
Postglacial	U172063	1599996	GRAB VAN VEEN	-32.90000	114.80833	1.64	88.55	9.81
Postglacial	U172109	1600041	GRAB VAN VEEN	-32.75000	114.96667	1.31	87.72	10.97
Postglacial	U172110	1600042	GRAB VAN VEEN	-32.73333	114.91667	2.59	89.62	7.79
Postglacial	U172113	1600045	GRAB VAN VEEN	-32.58333	114.98333	5.34	80.18	14.47
Postglacial	U172114	1600046	GRAB VAN VEEN	-32.58333	115.05000	2.44	76.24	21.33
Postglacial	C169001	1600103	GRAB VAN VEEN	-32.05000	115.39167	0.06	87.46	12.48
Postglacial	C169003	1600105	GRAB VAN VEEN	-32.05833	115.29833	0.55	98.06	1.39
Postglacial	C169004	1600106	GRAB VAN VEEN	-32.05833	115.25000	2.93	92.71	4.37
Postglacial	C169005	1600107	GRAB VAN VEEN	-31.97500	115.53333	2.10	94.70	3.21
Postglacial	C169007	1600109	GRAB VAN VEEN	-31.93833	115.52778	0.05	99.49	0.46
Postglacial	C169010	1600112	GRAB VAN VEEN	-31.96389	115.35556	0.73	61.08	38.19
Postglacial	C169011	1600113	GRAB VAN VEEN	-31.97667	115.29500	0.39	99.45	0.16
Postglacial	C169016	1600118	GRAB VAN VEEN	-32.15000	115.31667	1.00	96.09	2.91
Postglacial	C169017	1600119	GRAB VAN VEEN	-32.16111	115.25833	0.21	98.57	1.22
Postglacial	C169018	1600120	GRAB VAN VEEN	-32.17500	115.17778	2.37	91.73	5.90
Postglacial	C170003	1600123	GRAB VAN VEEN	-32.20556	115.47778	0.35	33.07	66.58
Postglacial	C170005	1600125	GRAB VAN VEEN	-32.21111	115.38333	0.18	45.94	53.88

Survey Id	Sample Id	Sample No	Sample Type	Latitude	Longitude	Mud %	Sand %	Gravel %
Postglacial	C170010	1600130	GRAB VAN VEEN	-32.22361	115.16389	1.25	97.00	1.75
Postglacial	C170025	1600136	GRAB VAN VEEN	-32.27000	115.43167	0.02	98.42	1.55
Postglacial	C170028	1600139	GRAB VAN VEEN	-32.27917	115.30417	0.79	53.08	46.13
Postglacial	C170038	1600149	GRAB VAN VEEN	-32.33667	115.36500	0.54	10.30	89.16
Postglacial	C170042	1600153	GRAB VAN VEEN	-32.33500	115.20500	1.82	93.36	4.83
Postglacial	C170043	1600154	GRAB VAN VEEN	-32.35500	115.16500	0.08	99.55	0.38
Postglacial	C170048	1600159	GRAB VAN VEEN	-32.38833	115.57778	1.12	97.31	1.58
Postglacial	C170049	1600160	GRAB VAN VEEN	-32.39167	115.53833	0.06	92.98	6.97
Postglacial	C170079	1600190	GRAB VAN VEEN	-32.56389	115.37500	0.06	95.76	4.18
Postglacial	C170080	1600191	GRAB VAN VEEN	-32.56667	115.33333	0.02	97.54	2.44
Postglacial	C170081	1600192	GRAB VAN VEEN	-32.56667	115.29167	0.12	99.46	0.42
Postglacial	C170083	1600194	GRAB VAN VEEN	-32.57500	115.20833	0.08	91.31	8.61
Postglacial	C170084	1600195	GRAB VAN VEEN	-32.57778	115.16667	0.13	90.13	9.75
Postglacial	C170085	1600196	GRAB VAN VEEN	-32.58056	115.11944	0.05	64.67	35.28
Postglacial	C170094	1600205	GRAB VAN VEEN	-32.70000	115.09167	0.05	25.49	74.46
Postglacial	C170097	1600208	GRAB VAN VEEN	-32.76111	115.44167	1.18	40.36	58.46
Postglacial	C170101	1600212	GRAB VAN VEEN	-32.78056	115.20000	0.08	92.80	7.12
Postglacial	C170103	1600214	GRAB VAN VEEN	-32.78611	115.07500	0.04	85.16	14.81
Postglacial	C171003	1600220	GRAB VAN VEEN	-32.13333	115.17083	27.24	72.58	0.18
Postglacial	C171004	1600222	GRAB VAN VEEN	-32.22500	115.14583	3.72	93.49	2.79
GA-80	80DR/004	1396460	DREDGE UNSPECIFIED	-32.00333	114.95833	61.37	38.55	0.08
GA-80	80DR/005	1396464	DREDGE UNSPECIFIED	-32.01167	114.96667	77.57	22.43	0.00
GA-80	80DR/006	1396474	DREDGE UNSPECIFIED	-32.02783	114.99350	87.34	12.65	0.01
GA-80	80DR/008	1396477	DREDGE UNSPECIFIED	-32.04167	115.01883	87.92	12.07	0.01
GA-80	80DR/009	1396480	DREDGE UNSPECIFIED	-32.02833	114.97667	87.17	12.72	0.11
GA-80	80DR/010	1396483	DREDGE UNSPECIFIED	-31.98917	115.02500	87.43	12.55	0.02
GA-80	80DR/012	1396485	DREDGE UNSPECIFIED	-31.96167	115.07500	84.03	15.97	0.00
GA-80	80DR/013	1396486	DREDGE UNSPECIFIED	-32.06000	114.75000	75.33	22.55	2.11
GA-80	80DR/014	1396496	DREDGE UNSPECIFIED	-32.05167	114.75833	72.31	23.49	4.21
GA-80	80DR/015	1396511	DREDGE UNSPECIFIED	-32.10000	114.71667	91.22	8.72	0.06
GA-80	80DR/016	1396514	DREDGE	-32.10083	114.71667	90.67	9.21	0.12

Survey Id	Sample Id	Sample No	Sample Type	Latitude	Longitude	Mud %	Sand %	Gravel %
			UNSPECIFIED					
			DREDGE	-31.95667	114.73667			
GA-80	80DR/017	1396518	UNSPECIFIED			83.34	16.59	0.06
			DREDGE	-31.99667	114.65833			
GA-80	80DR/018	1396522	UNSPECIFIED			91.68	8.32	0.00
			DREDGE	-32.00000	114.63333			
GA-80	80DR/019	1396525	UNSPECIFIED			90.32	9.62	0.06
			DREDGE	-31.83417	114.62667			
GA-80	80DR/020	1396530	UNSPECIFIED			84.61	15.39	0.00
			DREDGE	-31.80000	114.65000			
GA-80	80DR/021	1396542	UNSPECIFIED			83.81	15.14	1.05
			DREDGE	-31.89000	114.57500			
GA-80	80DR/023	1396551	UNSPECIFIED			84.35	15.65	0.00
	80/GC08		CORE	-31.87000	114.92333			
GA-80	0-2cm	1694858	GRAVITY			69.12	30.86	0.01

Table 10.4: Surveys

eno	Survey Id	Survey Name
348711	SS08/2005	Seabed Habitats and Geological Structure of the Northern Naturaliste Plateau, Southwest Australia
364060	FR 01/96	Holocene Biogenic Sedimentation, Northern Rottnest Shelf, Western
421	GA-80	South Perth Basin 1
261486	SS07/2005	Mapping benthic ecosystems on the deep continental shelf and slope in Australia's South West Region to understand evolution and biogeography and suppo rt implementation of the SW Regional Marine Plan and Commonwealth Marine Protected Areas. (Leg 1)
40905	Postglacial	Postglacial sediments and historys, Southern Rottnest Shelf, WA.

Table 10.5: Vlaming Sub-basin surface samples carbonate analysis

Survey Id	Sample Id	Sample No	Sample Type	Latitude	Longitude	Mud Carb %	Sand Carb %	Grave Carb %l	Bulk Carb %
FR 01/96	FR01/96DR 1	1746217	DREDGE PIPE	-31.75000	115.40017	0.00	78.79	95.00	73.68
FR 01/96	FR01/96DR 2	1746218	DREDGE PIPE	-31.75250	115.26617	0.00	95.04	95.00	93.59
FR 01/96	FR01/96DR 3	1746219	DREDGE PIPE	-31.75583	115.15650	0.00	94.02	100.00	93.34
FR 01/96	FR01/96DR 4	1746220	DREDGE PIPE	-31.47700	115.43450	0.00	87.13	100.00	83.98
FR 01/96	FR01/96DR 6	1746221	DREDGE PIPE	-31.59533	115.21350	0.00	96.91	95.00	95.55
FR 01/96	FR01/96DR 7	1746222	DREDGE BENTHIC	-31.64500	115.13083	0.00	94.61	100.00	92.91
FR 01/96	FR01/96DR 8	1746223	DREDGE BENTHIC	-31.69733	115.05083	0.00	95.12	100.00	94.19
SS08/2005	SS082005 01GR02	1682918	GRAB SMITH MCINTYRE	-32.04547	115.44532	0.00	93.88	100.00	92.66
SS08/2005	SS082005 01GR03	1682919	GRAB SMITH MCINTYRE	-32.04532	115.44532	0.00	91.19	100.00	90.23
SS08/2005	SS082005 02GC23 0-2cm	1694985	CORE GRAVITY	-32.05150	114.64853	82.74	0.00	0.00	79.74
SS08/2005	SS082005 02GC24	1694986	CORE GRAVITY	-32.04295	114.65833	82.31	0.00	0.00	79.31

Survey Id	Sample Id	Sample No	Sample Type	Latitude	Longitude	Mud Carb %	Sand Carb %	Grave Carb %l	Bulk Carb %
	0-2cm								
SS08/2005	SS082005 26GC21 0-2cm	1695000	CORE GRAVITY	-31.97215	114.60263	81.54	0.00	0.00	80.94
SS08/2005	SS082005 28GC22 0-2cm	1695002	CORE GRAVITY	-32.06507	114.66807	80.85	0.00	0.00	77.68
SS 07/2005	296/34GR35	1680496	GRAB SMITH MCINTYRE	-31.69710	114.87808	85.90	86.42	100.00	84.19
SS 07/2005	296/35GR36	1680497	GRAB SMITH MCINTYRE	-31.72708	114.75668	85.73	91.81	100.00	86.16
SS 07/2005	296/50GR51	1680512	GRAB SMITH MCINTYRE	-31.85337	115.02158	86.59	89.76	100.00	86.67
SS 07/2005	296/31GR32A	1680528	GRAB SMITH MCINTYRE	-31.61193	115.17823	0.00	96.44	100.00	92.07
Postglacial	U172006	1599944	GRAB VAN VEEN	-33.22500	115.30833	0.00	24.41	25.00	24.58
Postglacial	U172027	1599960	GRAB VAN VEEN	-33.30000	115.11667	0.00	70.40	85.00	66.89
Postglacial	U172042	1599975	GRAB VAN VEEN	-33.37500	115.25833	0.00	11.48	95.00	23.04
Postglacial	U172043	1599976	GRAB VAN VEEN	-33.33333	115.27500	0.00	42.31	90.00	43.77
Postglacial	U172044	1599977	GRAB VAN VEEN	-33.28333	115.30000	0.00	17.99	55.00	23.81
Postglacial	U172045	1599978	GRAB VAN VEEN	-33.30833	115.35833	0.00	14.47	95.00	13.28
Postglacial	U172046	1599979	GRAB VAN VEEN	-33.31667	115.41667	0.00	32.29	45.00	33.32
Postglacial	U172056	1599989	GRAB VAN VEEN	-33.05000	115.31667	0.00	19.36	90.00	22.78
Postglacial	U172063	1599996	GRAB VAN VEEN	-32.90000	114.80833	0.00	92.76	95.00	90.36
Postglacial	U172109	1600041	GRAB VAN VEEN	-32.75000	114.96667	0.00	92.50	95.00	90.27
Postglacial	U172110	1600042	GRAB VAN VEEN	-32.73333	114.91667	0.00	94.30	100.00	91.90
Postglacial	U172113	1600045	GRAB VAN VEEN	-32.58333	114.98333	0.00	92.76	100.00	90.87
Postglacial	U172114	1600046	GRAB VAN VEEN	-32.58333	115.05000	0.00	92.41	100.00	91.47
Postglacial	C169001	1600103	GRAB VAN VEEN	-32.05000	115.39167	0.00	92.16	100.00	90.53
Postglacial	C169003	1600105	GRAB VAN VEEN	-32.05833	115.29833	0.00	88.99	100.00	86.85
Postglacial	C169004	1600106	GRAB VAN VEEN	-32.05833	115.25000	0.00	91.30	100.00	89.59
Postglacial	C169005	1600107	GRAB VAN VEEN	-31.97500	115.53333	0.00	88.82	100.00	86.93
Postglacial	C169007	1600109	GRAB VAN VEEN	-31.93833	115.52778	0.00	68.35	100.00	69.03
Postglacial	C169010	1600112	GRAB VAN VEEN	-31.96389	115.35556	0.00	92.24	95.00	91.81
Postglacial	C169011	1600113	GRAB VAN VEEN	-31.97667	115.29500	0.00	92.93	100.00	90.96
Postglacial	C169016	1600118	GRAB VAN	-32.15000	115.31667	0.00	89.42	100.00	87.02

Survey Id	Sample Id	Sample No	Sample Type	Latitude	Longitude	Mud Carb %	Sand Carb %	Grave Carb %l	Bulk Carb %
			VEEN						
Postglacial	C169017	1600119	GRAB VAN VEEN	-32.16111	115.25833	0.00	88.90	100.00	86.59
Postglacial	C169018	1600120	GRAB VAN VEEN	-32.17500	115.17778	0.00	90.53	100.00	89.76
Postglacial	C170003	1600123	GRAB VAN VEEN	-32.20556	115.47778	0.00	92.16	80.00	91.21
Postglacial	C170005	1600125	GRAB VAN VEEN	-32.21111	115.38333	0.00	95.84	95.00	95.67
Postglacial	C170010	1600130	GRAB VAN VEEN	-32.22361	115.16389	0.00	90.10	100.00	89.33
Postglacial	C170025	1600136	GRAB VAN VEEN	-32.27000	115.43167	0.00	94.47	95.00	94.04
Postglacial	C170028	1600139	GRAB VAN VEEN	-32.27917	115.30417	0.00	94.64	100.00	94.73
Postglacial	C170038	1600149	GRAB VAN VEEN	-32.33667	115.36500	0.00	82.65	65.00	85.90
Postglacial	C170042	1600153	GRAB VAN VEEN	-32.33500	115.20500	0.00	92.07	100.00	90.27
Postglacial	C170043	1600154	GRAB VAN VEEN	-32.35500	115.16500	0.00	90.96	100.00	90.87
Postglacial	C170048	1600159	GRAB VAN VEEN	-32.38833	115.57778	0.00	79.74	80.00	78.88
Postglacial	C170049	1600160	GRAB VAN VEEN	-32.39167	115.53833	0.00	40.34	85.00	43.59
Postglacial	C170069	1600180	GRAB VAN VEEN	-32.48056	115.39167	0.00	0.00	0.00	87.40
Postglacial	C170079	1600190	GRAB VAN VEEN	-32.56389	115.37500	0.00	27.49	60.00	40.51
Postglacial	C170080	1600191	GRAB VAN VEEN	-32.56667	115.33333	0.00	37.26	45.00	32.20
Postglacial	C170081	1600192	GRAB VAN VEEN	-32.56667	115.29167	0.00	89.50	100.00	85.99
Postglacial	C170083	1600194	GRAB VAN VEEN	-32.57500	115.20833	0.00	95.15	85.00	93.44
Postglacial	C170084	1600195	GRAB VAN VEEN	-32.57778	115.16667	0.00	95.58	100.00	94.81
Postglacial	C170085	1600196	GRAB VAN VEEN	-32.58056	115.11944	0.00	95.50	100.00	94.55
Postglacial	C170094	1600205	GRAB VAN VEEN	-32.70000	115.09167	0.00	96.10	100.00	94.98
Postglacial	C170101	1600212	GRAB VAN VEEN	-32.78056	115.20000	0.00	78.71	25.00	77.25
Postglacial	C170103	1600214	GRAB VAN VEEN	-32.78611	115.07500	0.00	94.55	100.00	94.55
Postglacial	C171003	1600220	GRAB VAN VEEN	-32.13333	115.17083	87.45	90.02	100.00	87.27
Postglacial	C171004	1600222	GRAB VAN VEEN	-32.22500	115.14583	0.00	91.04	100.00	89.67
GA-80	80DR/004	1396460	DREDGE UN SPECIFIED	-32.00333	114.95833	87.70	93.36	100.00	87.79
GA-80	80DR/005	1396464	DREDGE UN SPECIFIED	-32.01167	114.96667	58.15	47.36	0.00	51.82
GA-80	80DR/006	1396474	DREDGE UN SPECIFIED	-32.02783	114.99350	84.96	89.84	100.00	81.79
GA-80	80DR/008	1396477	DREDGE UN	-32.04167	115.01883	85.99	89.50	100.00	82.48

Survey Id	Sample Id	Sample No	Sample Type	Latitude	Longitude	Mud Carb %	Sand Carb %	Grave Carb %l	Bulk Carb %
			SPECIFIED DREDGE						
GA-80	80DR/009	1396480	UN SPECIFIED DREDGE	-32.02833	114.97667	83.33	87.87	100.00	81.54
GA-80	80DR/010	1396483	UN SPECIFIED DREDGE	-31.98917	115.02500	83.68	89.33	100.00	82.39
GA-80	80DR/012	1396485	UN SPECIFIED DREDGE	-31.96167	115.07500	83.93	88.64	0.00	82.82
GA-80	80DR/013	1396486	UN SPECIFIED DREDGE	-32.06000	114.75000	71.17	32.63	10.00	76.31
GA-80	80DR/014	1396496	UN SPECIFIED DREDGE	-32.05167	114.75833	72.89	41.97	10.00	78.45
GA-80	80DR/015	1396511	UN SPECIFIED DREDGE	-32.10000	114.71667	81.36	82.48	100.00	77.34
GA-80	80DR/016	1396514	UN SPECIFIED DREDGE	-32.10083	114.71667	81.45	81.19	0.00	78.20
GA-80	80DR/017	1396518	UN SPECIFIED DREDGE	-31.95667	114.73667	79.91	90.53	100.00	77.43
GA-80	80DR/018	1396522	UN SPECIFIED DREDGE	-31.99667	114.65833	81.45	89.24	0.00	76.40
GA-80	80DR/019	1396525	UN SPECIFIED DREDGE	-32.00000	114.63333	82.39	86.93	100.00	79.39
GA-80	80DR/020	1396530	UN SPECIFIED DREDGE	-31.83417	114.62667	79.31	81.36	0.00	75.71
GA-80	80DR/021	1396542	UN SPECIFIED DREDGE	-31.80000	114.65000	77.08	68.86	100.00	74.34
GA-80	80DR/023	1396551	UN SPECIFIED	-31.89000	114.57500	80.94	84.11	0.00	80.17
GA-80	80/GC08/0-2cm	1694858	CORE GRAVITY	-31.87000	114.92333	85.82	92.26	100.00	78.20

10.2.2 Mentelle Basin Sediment Samples

WESTERN MENTELLE SUB-BASIN

One core top sample and one down core sample were extracted from the MARS database in the Western Mentelle Sub-Basin. These were located in the east and west of the basin. They were collected by piston core during Conrad Cruise Leg 8 (western sample) and Eltanin Cruise 45 (eastern samples, 2 samples 0 – 3 cm, 6 – 8cm). All samples are sandy mud (78 – 88% mud, 12 – 22% sand) with no gravel content. The sediments are carbonate-rich, with 78 – 90% carbonate in bulk sample and 82 – 92 % carbonate in the mud fraction. There was only one sample analysed in the east, yielding sand fraction carbonate content of 88%.

Table 10.6: Western Mentelle Sub-basin Grainsize, surface samples.

Survey Name	Sample Id	Sample No	Sample Type	Latitude	Longitude	Mud %	Sand %	Gravel %
Eltanin Cruise 45	ELT45 TC102 0-3	1747796	CORE PISTON	-33.61300	113.58500	80.27	19.73	0.00

Table 10.7: Western Mentelle Sub-basin Carbonate, surface samples.

Survey Name	Sample Id	Sample No	Sample Type	Latitude	Longitude	Mud Carb %	Sand Carb %	Gravel Carb %	Bulk Carb %
Eltanin Cruise 45	ELT45 TC102 0-3	1747796	CORE PISTON	-33.61300	113.58500	82.45	0.00	0.00	77.90

EASTERN MENTELLE SUB-BASIN

386 samples were identified in the eastern Mentelle Sub-basin. The majority were collected from one survey, SS08/2005 across 18 sites. There are 18 surface samples in the area, collected in the north by gravity core during survey SS08/2005.

The surface samples comprise carbonate-rich sandy mud. On average, mud comprises 81% of the total sediment grainsize. Samples ranged from 64 to 91 % mud. Sand comprises an average of 19% of the total sediments and ranging 9 - 35%. Gravel forms a minor component of the sediment, with an average of 0.08% (range: 0 – 0.7%).

Table 10.8: Eastern Mentelle Sub-basin Grainsize, Surface Sediments.

Survey Id	Sample Id	Sample No	Sample Type	Latitude	Longitude	Mud %	Sand %	Gravel %
SS08/2005	SS082005 03GC12 0-2cm	1694987	CORE GRAVITY	-32.83060	113.90080	80.40	19.60	0.00
SS08/2005	SS082005 04GC01 0-2cm	1694988	CORE GRAVITY	-32.60712	114.33732	64.24	35.59	0.17
SS08/2005	SS082005 09GC06 0-2cm	1694989	CORE GRAVITY	-32.89193	114.20580	79.47	20.53	0.00
SS08/2005	SS082005 10GC08 0-2cm	1694990	CORE GRAVITY	-32.79660	114.16548	72.11	27.89	0.00
SS08/2005	SS082005 11GC10 0-2cm	1694991	CORE GRAVITY	-32.80583	113.80480	68.33	31.67	0.00
SS08/2005	SS082005 12GC13 0-2cm	1694992	CORE GRAVITY	-32.82622	113.85638	77.35	22.65	0.00
SS08/2005	SS082005 17GC14 0-2cm	1694993	CORE GRAVITY	-32.93572	113.88700	77.24	22.76	0.00
SS08/2005	SS082005 18GC15 0-2cm	1694994	CORE GRAVITY	-32.96750	113.89795	80.10	19.56	0.34

Survey Id	Sample Id	Sample No	Sample Type	Latitude	Longitude	Mud %	Sand %	Gravel %
SS08/2005	SS082005 19GC16 0-2cm	1694995	CORE GRAVITY	-32.98750	113.89407	85.54	14.31	0.15
SS08/2005	SS082005 21GC17 0-2cm	1694996	CORE GRAVITY	-32.94662	113.93027	90.87	9.13	0.00
SS08/2005	SS082005 24GC18 0-2cm	1694997	CORE GRAVITY	-32.77393	114.14127	75.02	24.98	0.00
SS08/2005	SS082005 23GC18A 0-2cm	1694998	CORE GRAVITY	-32.78237	114.14752	79.16	20.17	0.67
SS08/2005	SS082005 25GC19 0-2cm	1694999	CORE GRAVITY	-32.86000	114.25028	88.89	11.11	0.00
SS08/2005	SS082005 27GC20 0-2cm	1695001	CORE GRAVITY	-32.62148	114.42117	83.40	16.51	0.09
SS08/2005	SS082005 08GC05 0-2cm	1695003	CORE GRAVITY	-32.55445	114.32323	84.18	15.82	0.00
SS08/2005	SS082005 06GC03 0-2cm	1695004	CORE GRAVITY	-32.57615	114.35628	88.77	11.23	0.00
SS08/2005	SS082005 05GC02 0-2cm	1695005	CORE GRAVITY	-32.58735	114.36272	88.81	11.19	0.00
SS08/2005	SS082005 07GC04 0-2cm	1695006	CORE GRAVITY	-32.52835	114.30740	90.87	9.13	0.00

Table 10.9: Eastern Mentelle Sub-basin Carbonate, Surface Samples

Survey Id	Sample Id	Sample No	Sample Type	Latitude	Longitude	Mud Carb %	Sand Carb %	Gravel Carb %	Bulk Carb %
SS08/2005	SS082005 03GC12 0-2cm	1694987	CORE GRAVITY	-32.83060	113.90080	82.22	91.64	0.00	81.88
SS08/2005	SS082005 04GC01 0-2cm	1694988	CORE GRAVITY	-32.60712	114.33732	87.45	94.04	100.00	87.87
SS08/2005	SS082005 09GC06 0-2cm	1694989	CORE GRAVITY	-32.89193	114.20580	86.08	0.00	0.00	84.96
SS08/2005	SS082005 10GC08 0-2cm	1694990	CORE GRAVITY	-32.79660	114.16548	81.28	0.00	0.00	81.36
SS08/2005	SS082005 11GC10 0-2cm	1694991	CORE GRAVITY	-32.80583	113.80480	78.80	92.93	0.00	79.82
SS08/2005	SS082005 12GC13 0-2cm	1694992	CORE GRAVITY	-32.82622	113.85638	82.91	0.00	0.00	82.39
SS08/2005	SS082005 17GC14 0-2cm	1694993	CORE GRAVITY	-32.93572	113.88700	84.19	92.50	0.00	83.16
SS08/2005	SS082005 18GC15 0-2cm	1694994	CORE GRAVITY	-32.96750	113.89795	83.33	90.61	100.00	83.16

SS08/2005	SS082005 19GC16 0-2cm	1694995	CORE GRAVITY	-32.98750	113.89407	82.74	88.99	100.00	82.56
SS08/2005	SS082005 21GC17 0-2cm	1694996	CORE GRAVITY	-32.94662	113.93027	83.68	91.04	0.00	83.85
SS08/2005	SS082005 24GC18 0-2cm	1694997	CORE GRAVITY	-32.77393	114.14127	83.59	0.00	0.00	80.42
SS08/2005	SS082005 23GC18A 0-2cm	1694998	CORE GRAVITY	-32.78237	114.14752	83.25	91.13	100.00	82.65
SS08/2005	SS082005 25GC19 0-2cm	1694999	CORE GRAVITY	-32.86000	114.25028	84.62	86.42	0.00	82.31
SS08/2005	SS082005 27GC20 0-2cm	1695001	CORE GRAVITY	-32.62148	114.42117	85.65	90.70	100.00	84.53
SS08/2005	SS082005 08GC05 0-2cm	1695003	CORE GRAVITY	-32.55445	114.32323	71.26	0.00	0.00	78.02
SS08/2005	SS082005 06GC03 0-2cm	1695004	CORE GRAVITY	-32.57615	114.35628	78.62	0.00	0.00	80.85
SS08/2005	SS082005 05GC02 0-2cm	1695005	CORE GRAVITY	-32.58735	114.36272	80.94	0.00	0.00	82.99
SS08/2005	SS082005 07GC04 0-2cm	1695006	CORE GRAVITY	-32.52835	114.30740	79.99	0.00	0.00	69.72

NB: the full title of survey SS08/2005 is "Seabed Habitats and Geological Structure of the Northern Naturaliste Plateau, Southwest Australia."

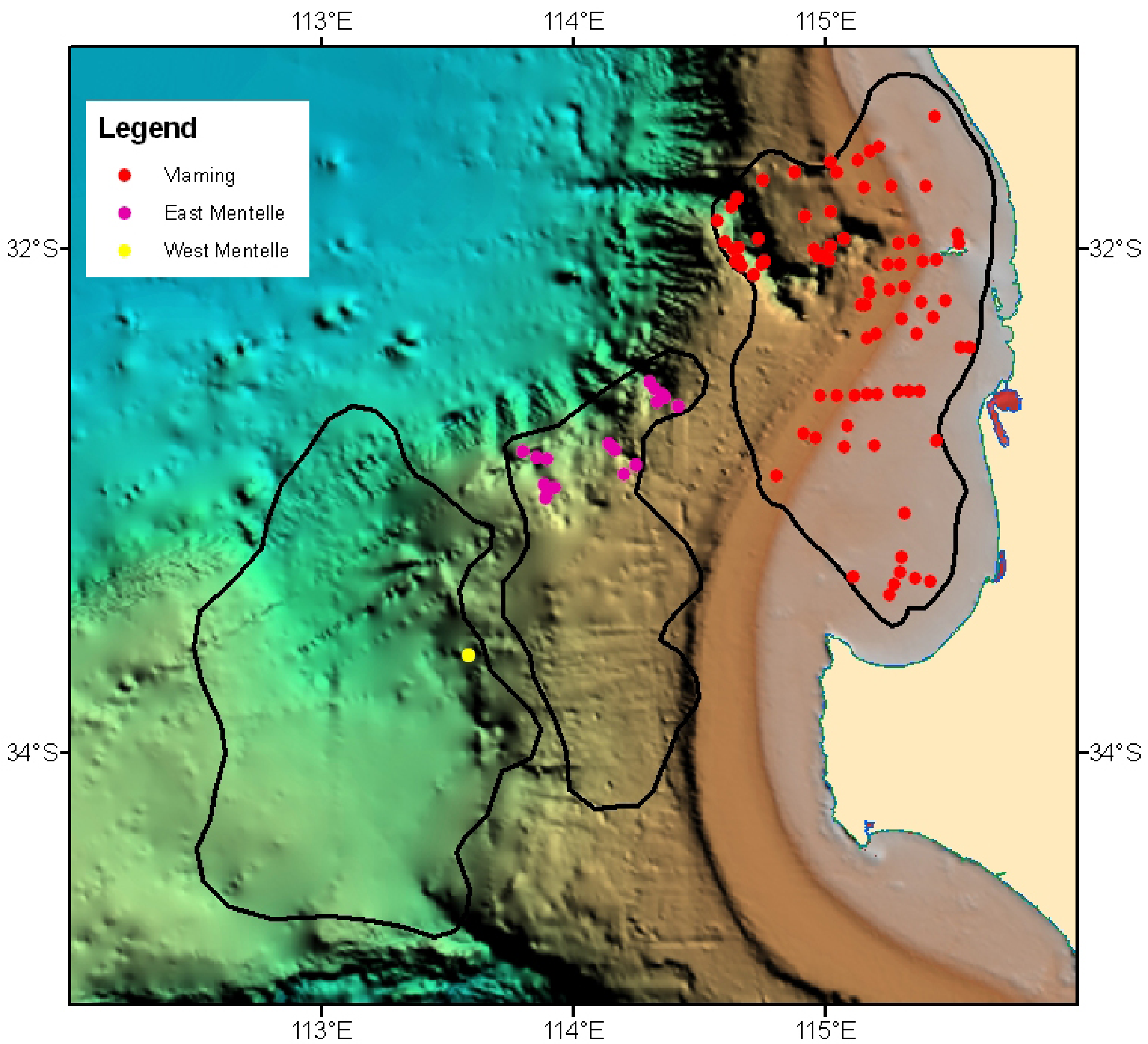


Figure 10.1: *Sample locations*

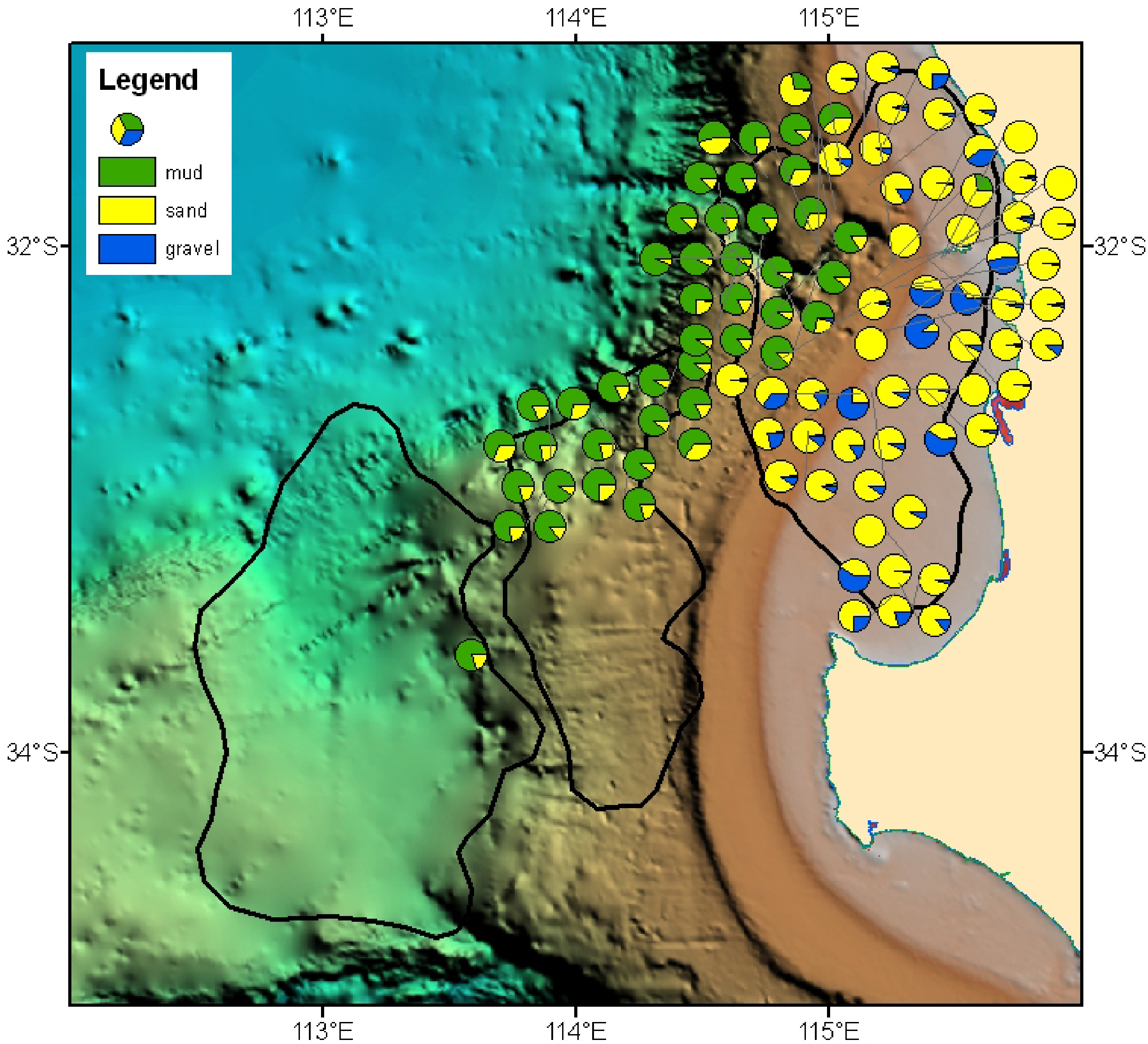


Figure 10.2: *Grainsize pie charts.*

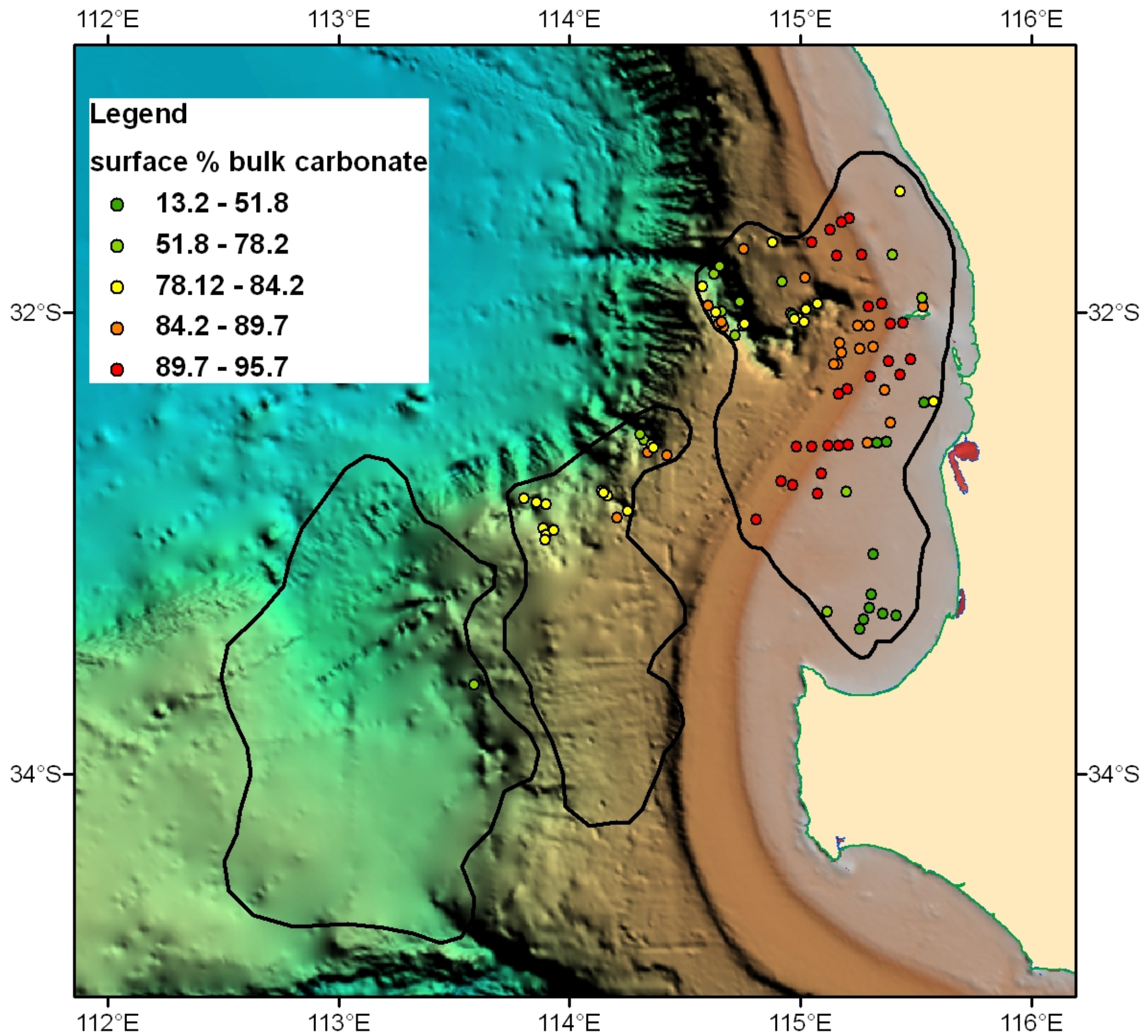


Figure 10.3: *Bulk carbonate percentage*